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# FULL SCALE CYCLIC LATERAL LOAD TESTS ON SIX SINGLE PILES IN SAND

by

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This study was performed to determine responses of single piles in sands subjected to cyclic lateral loading and compare the results with predicted responses based on in-situ pressuremeter tests. The pressuremeter method used for predicting pile response to monotonic lateral loading is applicable to piles which will experience little or no degradation in flexural stiffness such as steel piles and prestressed concrete piles loaded less than the prestress.


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# PREFACE

This study was performed by the Geotechnical Division, Civil Engineering Department, Texas A&M University, College Station, TX, under contract to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the US Army Engineer District, St. Louis. The study was performed under Contract No. DACW39-87-M-0446.

This report was prepared by Mr. Robert L. Little and Dr. Jean-Louis Briaud, Texas A&M University, and reviewed by Mr. G. Britt Mitchell, Chief, Engineering Group, Soil Mechanics Division (SMD), Geotechnical Laboratory (GL), WES. General supervision was provided by Mr. Clifford L. McAnear, Chief, SMD, and Dr. William F. Marcuson III, Chief, GL.

COL Dwayne G. Lee, EN, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

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# 1. INTRODUCTION

## 1.1 Project Purpose

Six existing piles were readily available for lateral load testing. The purpose of this project was to subject those six piles to cyclic horizontal loads and study the corresponding accumulation of horizontal displacement. These load tests also provided a unique opportunity to study the potential of the pressuremeter for predicting the response of piles in sand subjected to cyclic horizontal loads.

Pressuremeter tests offer an array of advantages over present day methods employed in the design of laterally-loaded piles. The pressuremeter method allows site specific P-y curves developed from point-by-point in-situ measurement to be obtained, rather than curves derived from one or two measured soil parameters. The pressuremeter is a versatile instrument and can be employed in virtually any soil type, including those for which there are no existing recommendations for the derivation of conventional P-y curves. The pressuremeter allows the pile installation method to be modelled directly: pre-bored pressuremeter tests for drilled shafts and driven pressuremeter tests for driven piles. The pressuremeter is also capable of simulating the expected pile loading conditions: sustained pressure increment tests, unload-reload cyclic tests and rapid inflation tests yield site-specific soil responses to creep loading, cyclic loading and dynamic loading respectively.

These advantages over existing methods prompted this project. The chief objective was to incorporate cyclic loading effects into the derivation of P-y curves obtained from pressuremeter tests in order to predict the response of piles in sand subjected to cyclic lateral loading.

## 1.2 Project Approach

This project was designed to allow for a comparison of measured responses of piles in sand subjected to cyclic lateral loading with predicted responses based on in-situ pressuremeter tests. The project was divided into three phases. In the first phase, a series of pressuremeter (PMT) tests were performed at a site where six individual piles had earlier been installed and load tested vertically. In the second phase, the piles were load tested under cyclic lateral loading and the responses were recorded. In the final phase, predictions of the pile response were prepared based on the PMT tests and the predictions were compared to the measured results.

# 2. THE SITE AND THE SOIL

## 2.1 Test Site Location

The pile load test site was located on property under the authority of the Texas State Department of Highways and Public Transportation at the northern end of the Baytown-La Porte tunnel on State Highway 146 near Houston, Texas (Figure 1). The six piles were arranged in a triangular pattern approximately 300 ft south of the tunnel maintenance building near Lagoon Number Three (Figure 2). The piles were originally installed for vertical pile capacity load testing in connection with the construction of a 100 million dollar cable-stayed bridge spanning the Houston ship channel at the same location.

## 2.2 Soil Conditions and Stratigraphy

A variety of soil tests had been previously performed at the site in conjunction with the vertical load testing of the piles (Briaud Engineers, 1986). The soil was primarily composed of loose to medium dense fine sand in the upper 73 ft underlain by stiff to very stiff clay (Figure 3). A boring log with Standard Penetration Test (SPT) results, grain size analysis curves and cone penetrometer test results are presented in Figures 4 through 6 to complete the documentation of the soil.

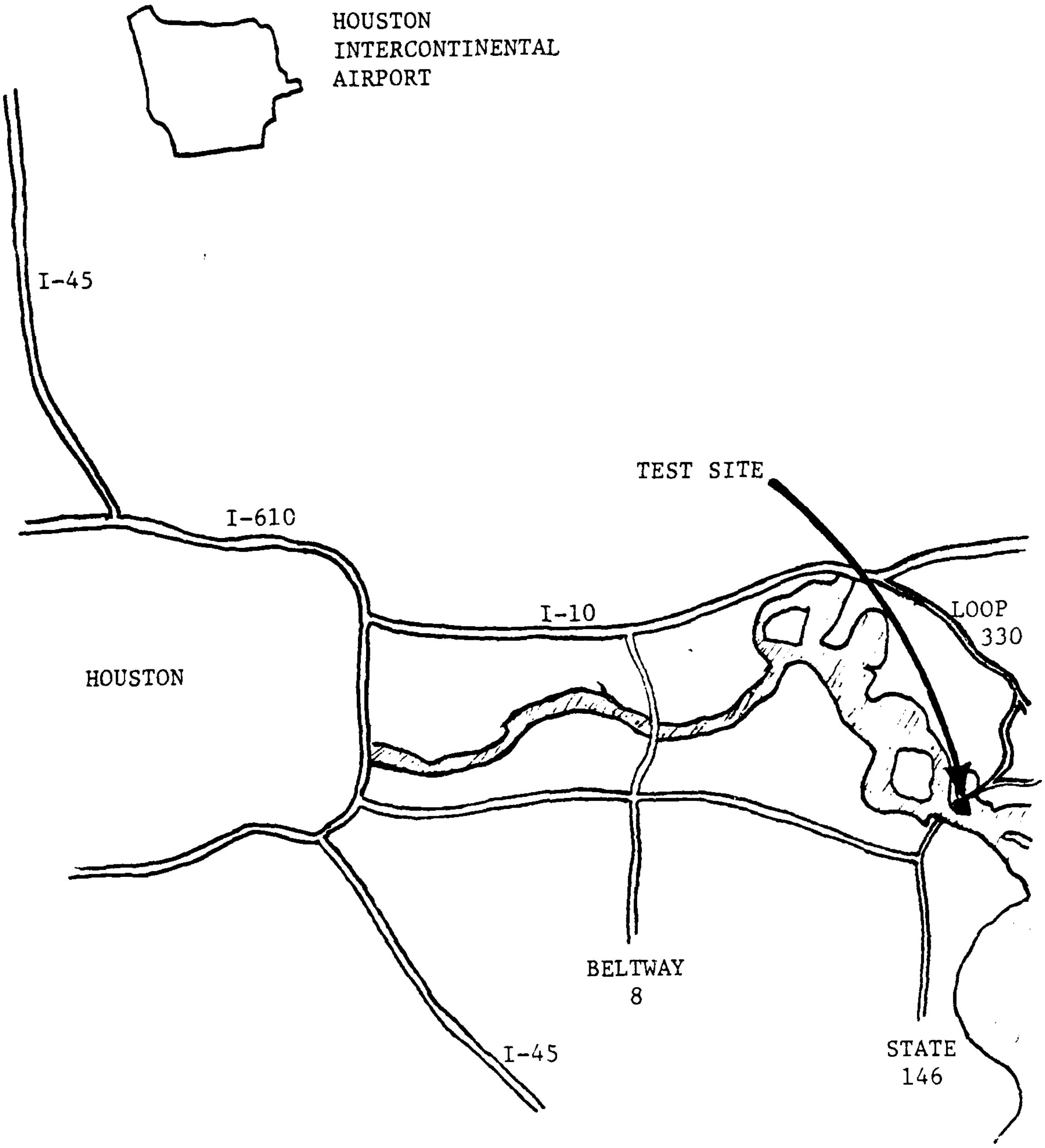



FIGURE 1. Location of Test Site

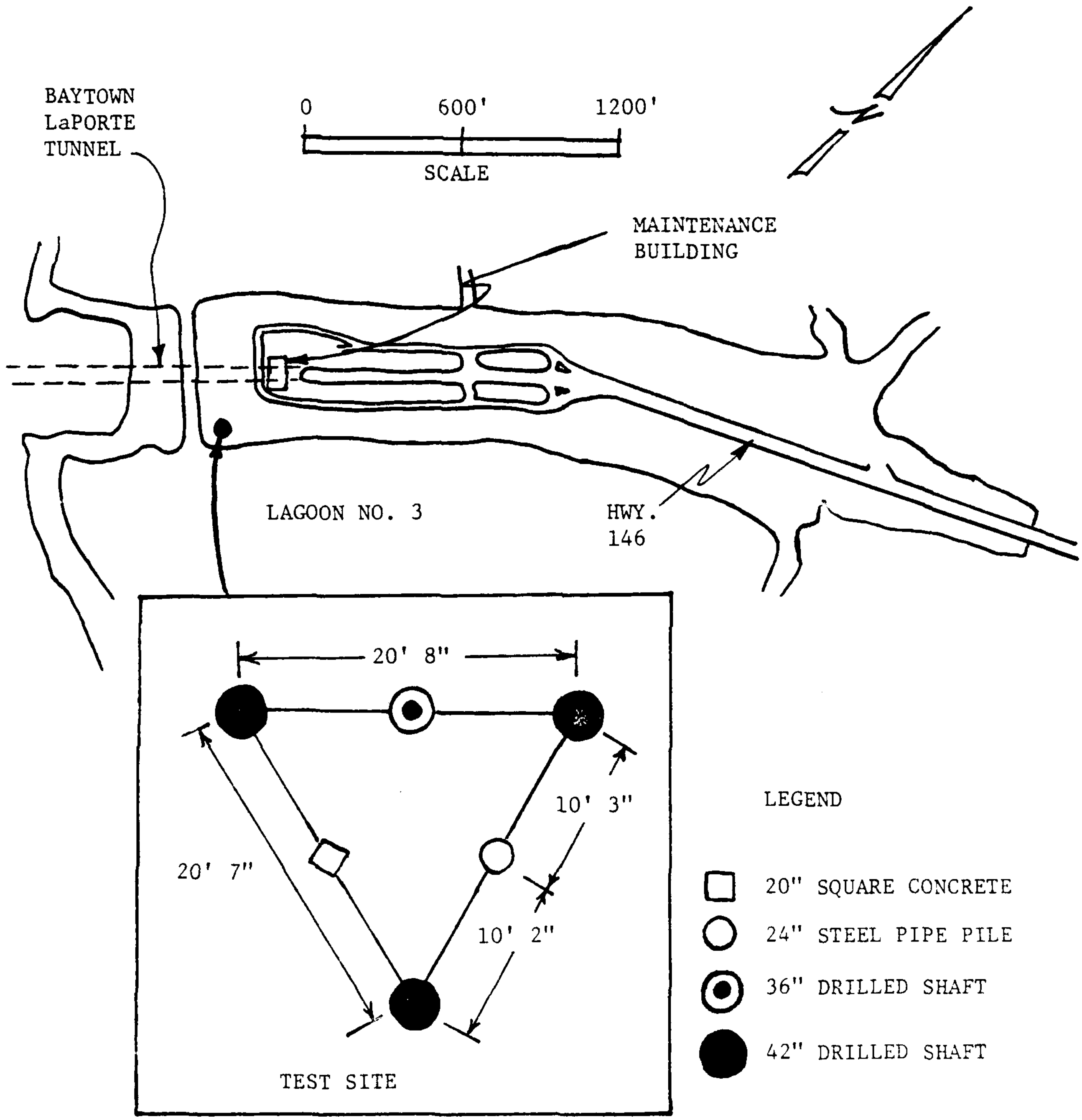



FIGURE 2. Site Plan and Arrangement of Test Piles

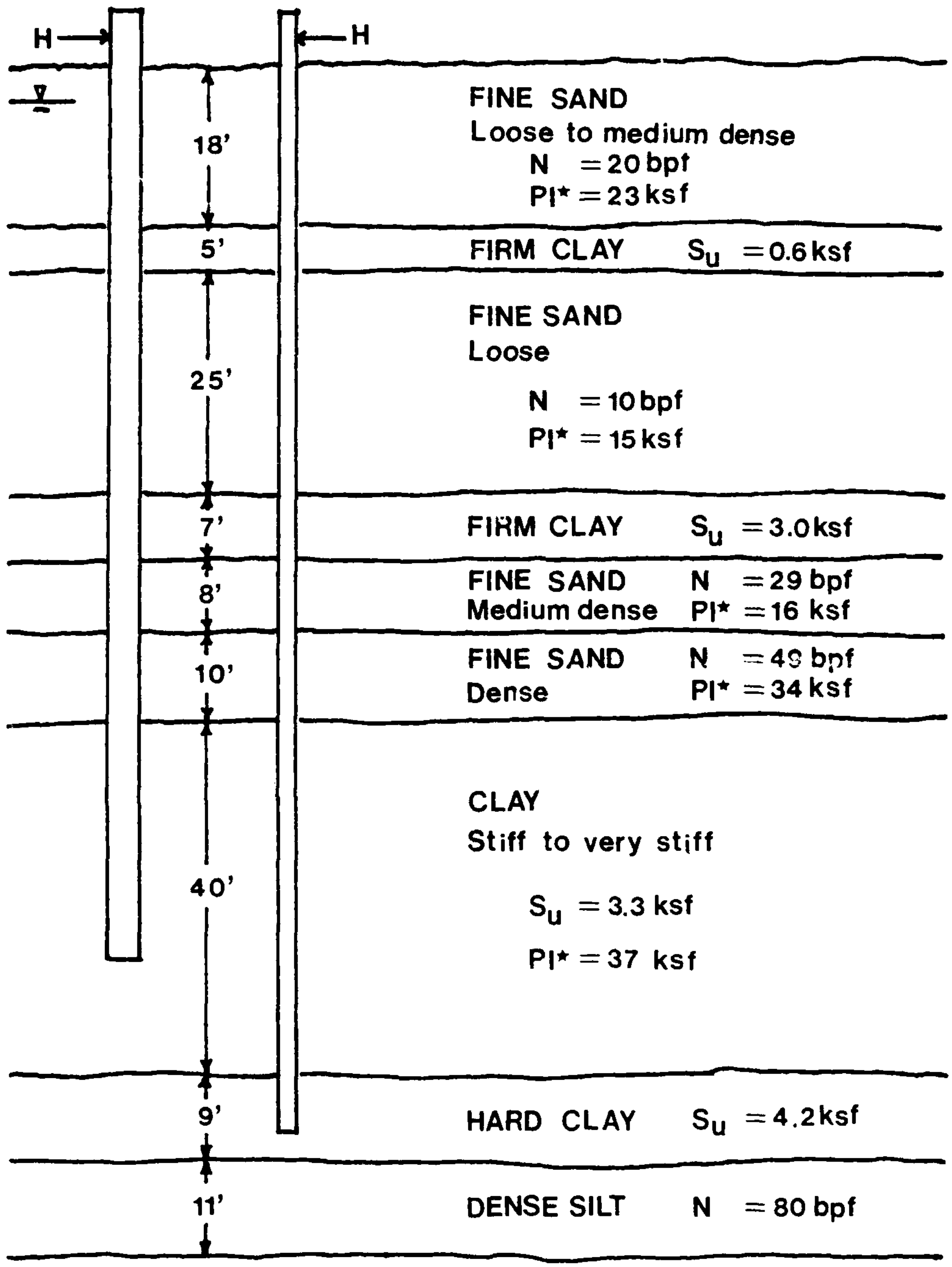



FIGURE 3. Soil Profile at Test Site

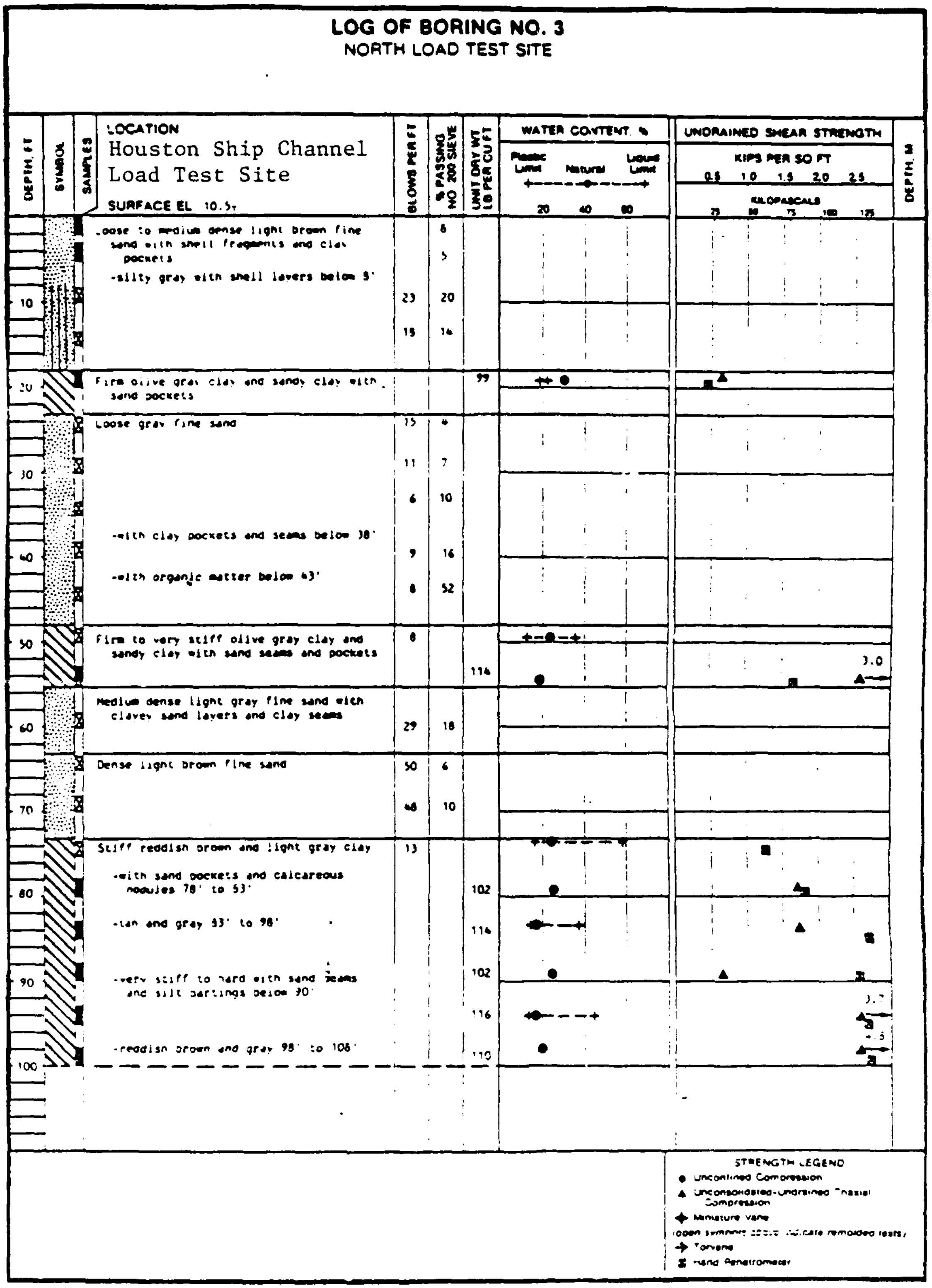



FIGURE 4a. Test Site Boring Log, 0' to 100'

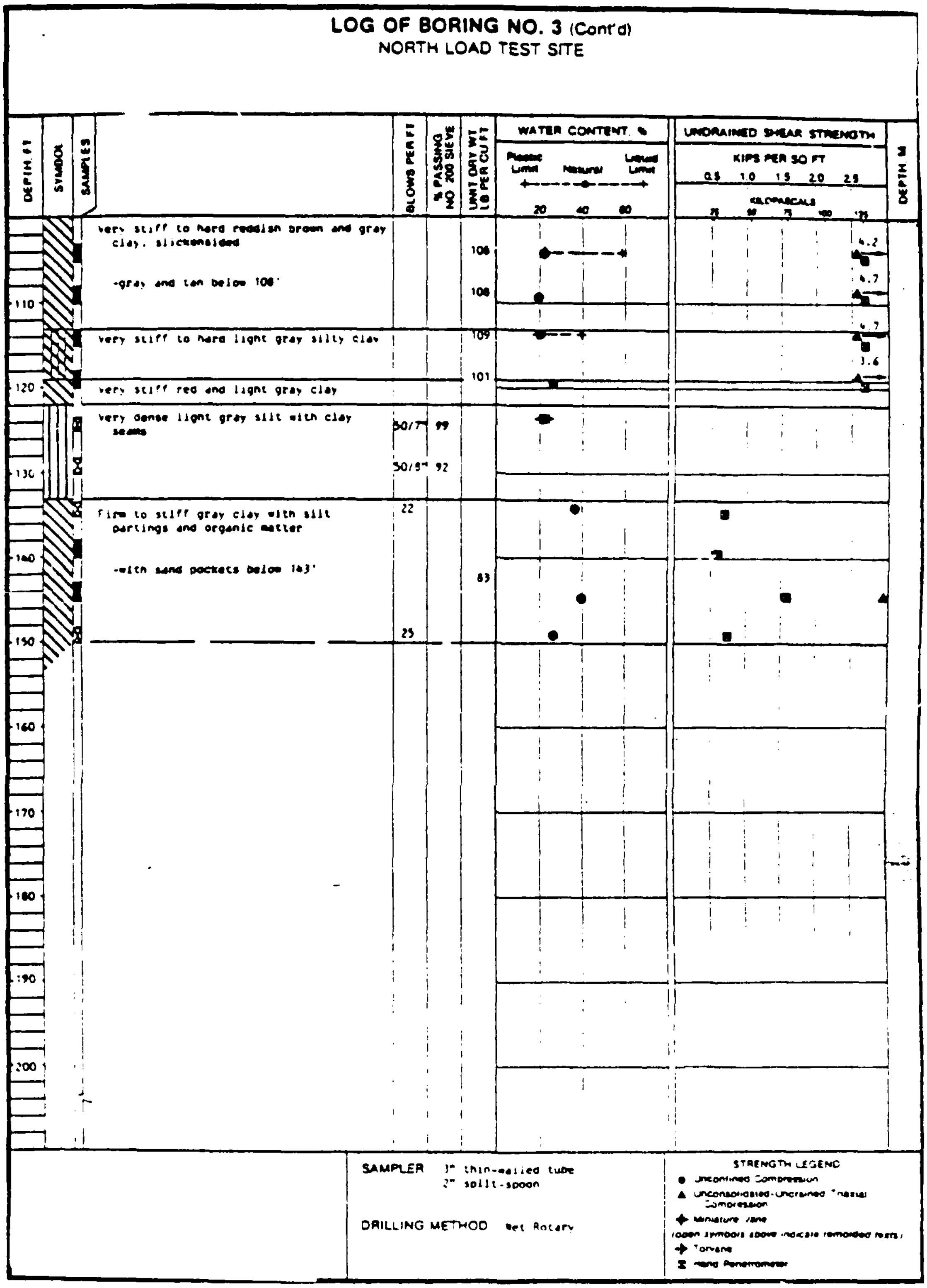
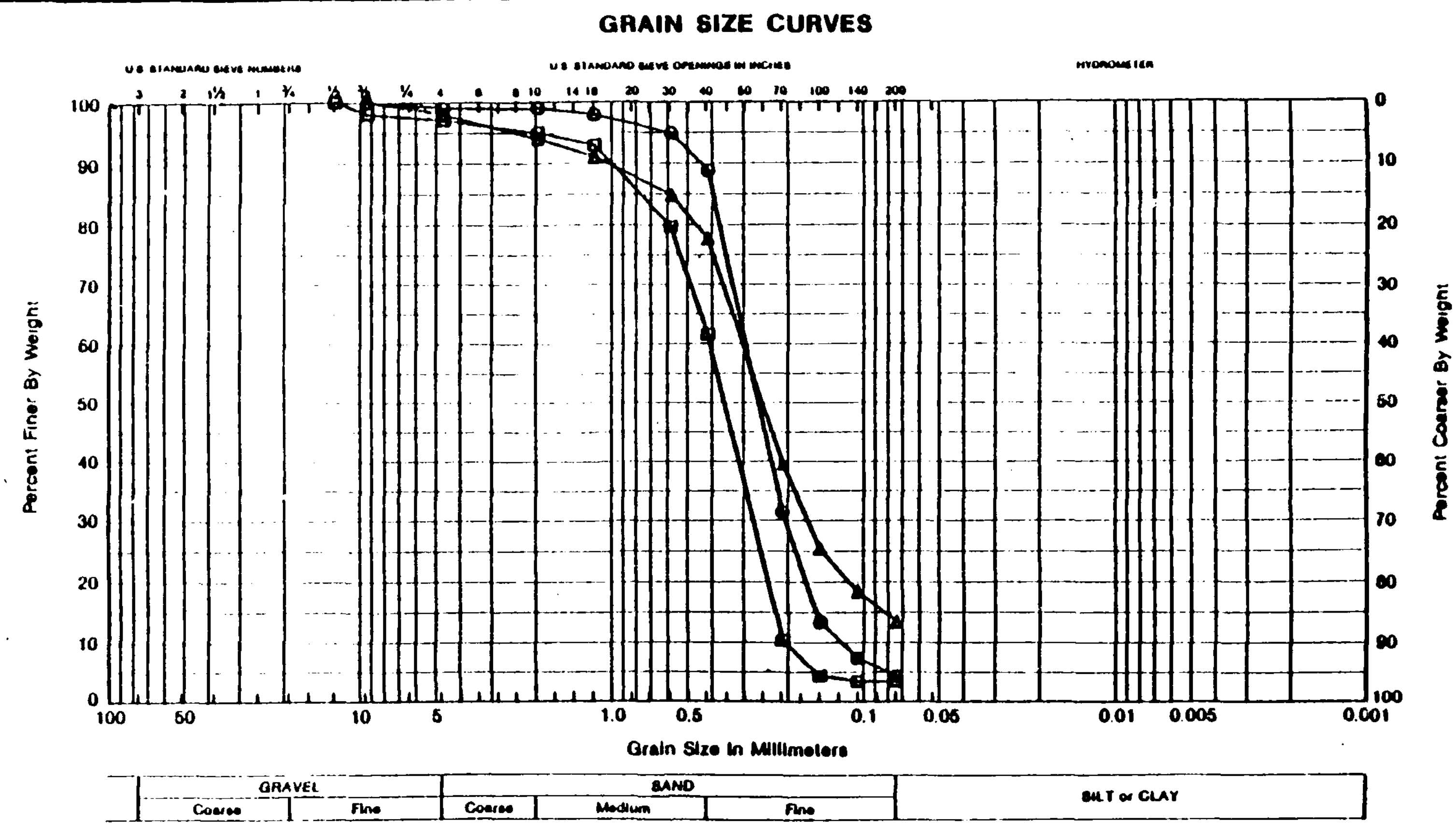
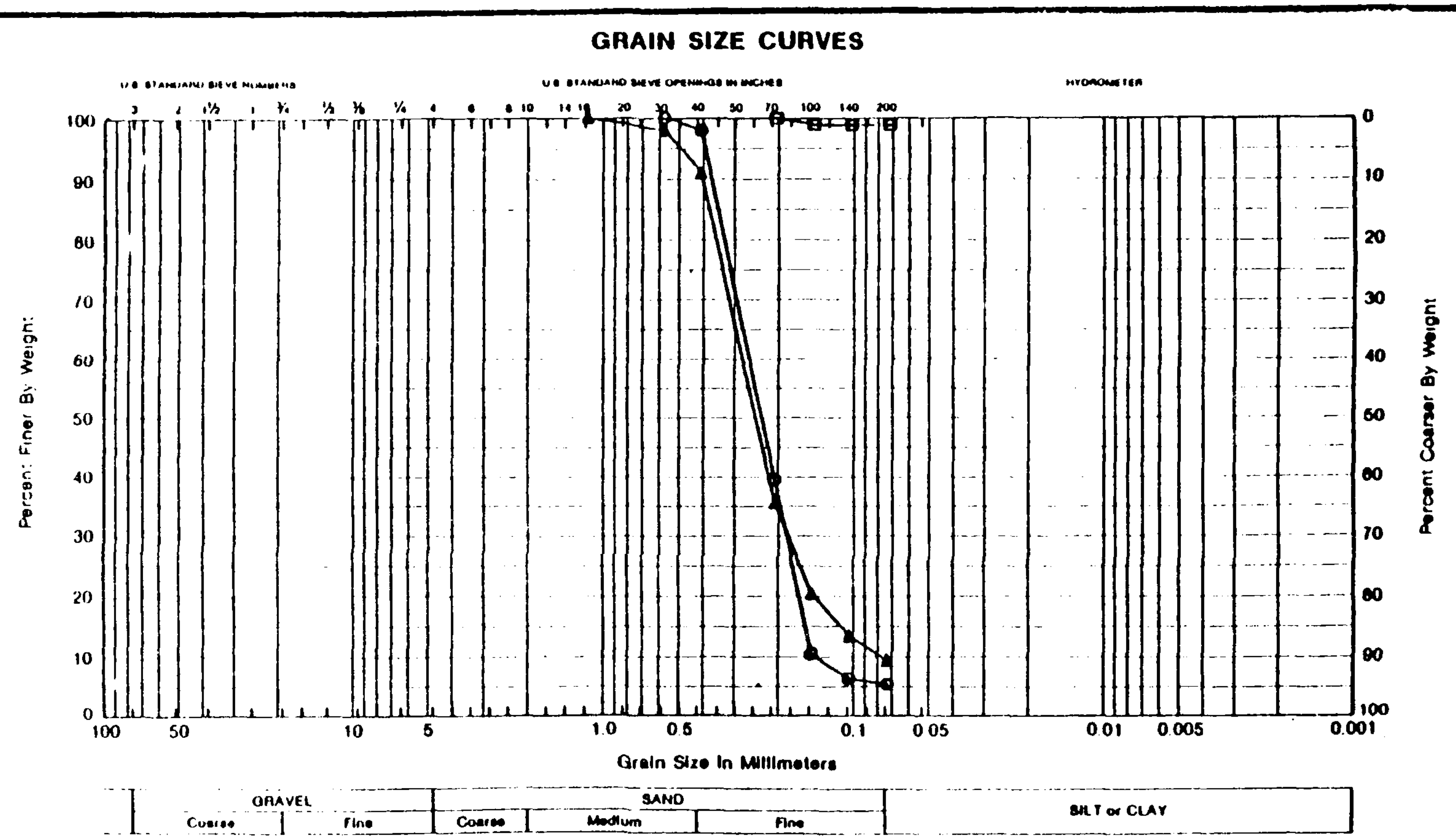



FIGURE 4b. Test Site Boring Log, 100' to 150'




| CURVE | BORING NO. | PENETRATION, Ft. | MATERIAL |
|---|---|---|---|
| -●-●-●- | 3 | 4.5 | Light brown fine sand with shell fragments |
| -▲-▲-▲- | 3 | 14.5 | Gray silty fine sand with shell fragments |
| -⊠-⊠-⊠- | 3 | 24.5 | Gray fine sand |

FIGURE 5a. Test Site Grain Size Curves, 0' to 24.5'




| CURVE | BORING NO. | PENETRATION, Ft. | MATERIAL |
|---|---|---|---|
| -●-●-●- | 3 | 64.5 | Brown fine sand |
| -▲-▲-▲- | 3 | 69.5 | Brown fine sand |
| -⊡-⊡-⊡- | 3 | 124 | Light gray silt |

FIGURE 5b. Test Site Grain Size Curves, 64.5' to 124'

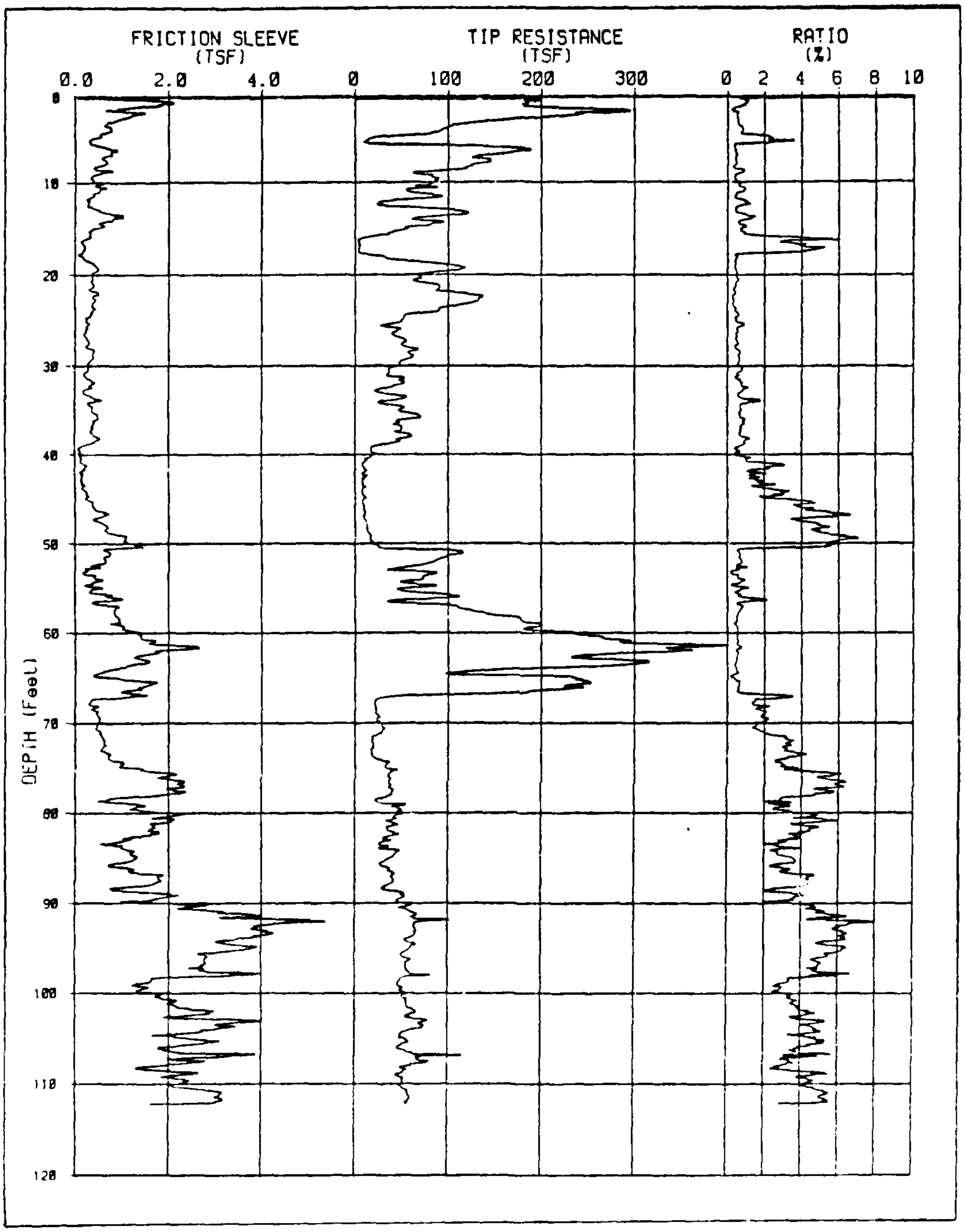



FIGURE 6a. Test Site Cone Penetrometer Data: CPT1

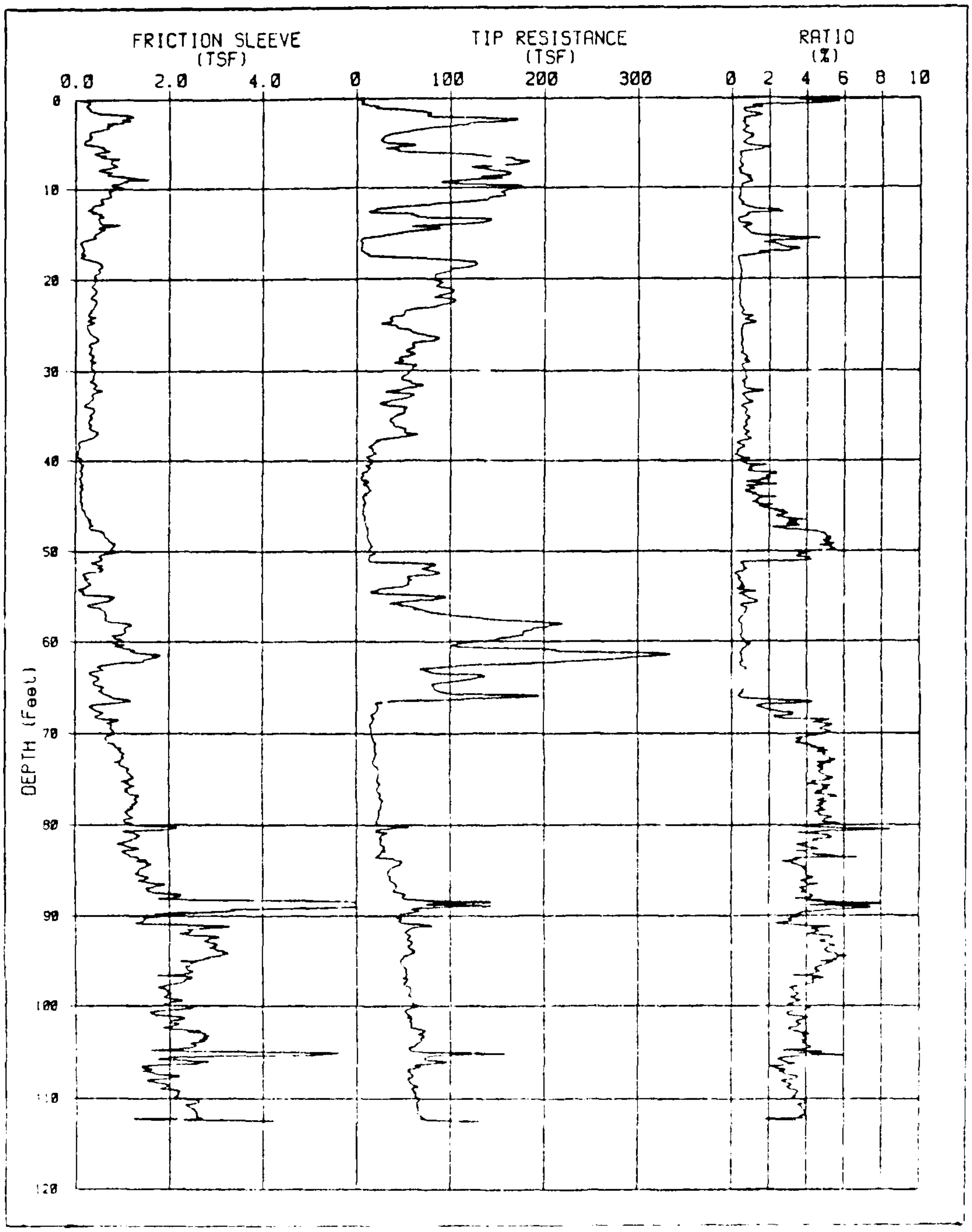



FIGURE 6b. Test Site Cone Penetrometer Data: CPT2

## 3. THE PILES

### 3.1 Layout of the Piles

The six piles at the load test site were arranged in a triangular pattern as shown in Figure 7. This layout was selected at the time the piles were installed to load test vertically the three smaller piles on the legs of the triangle. The three 42-in diameter shafts in the corners were used for vertical reaction.

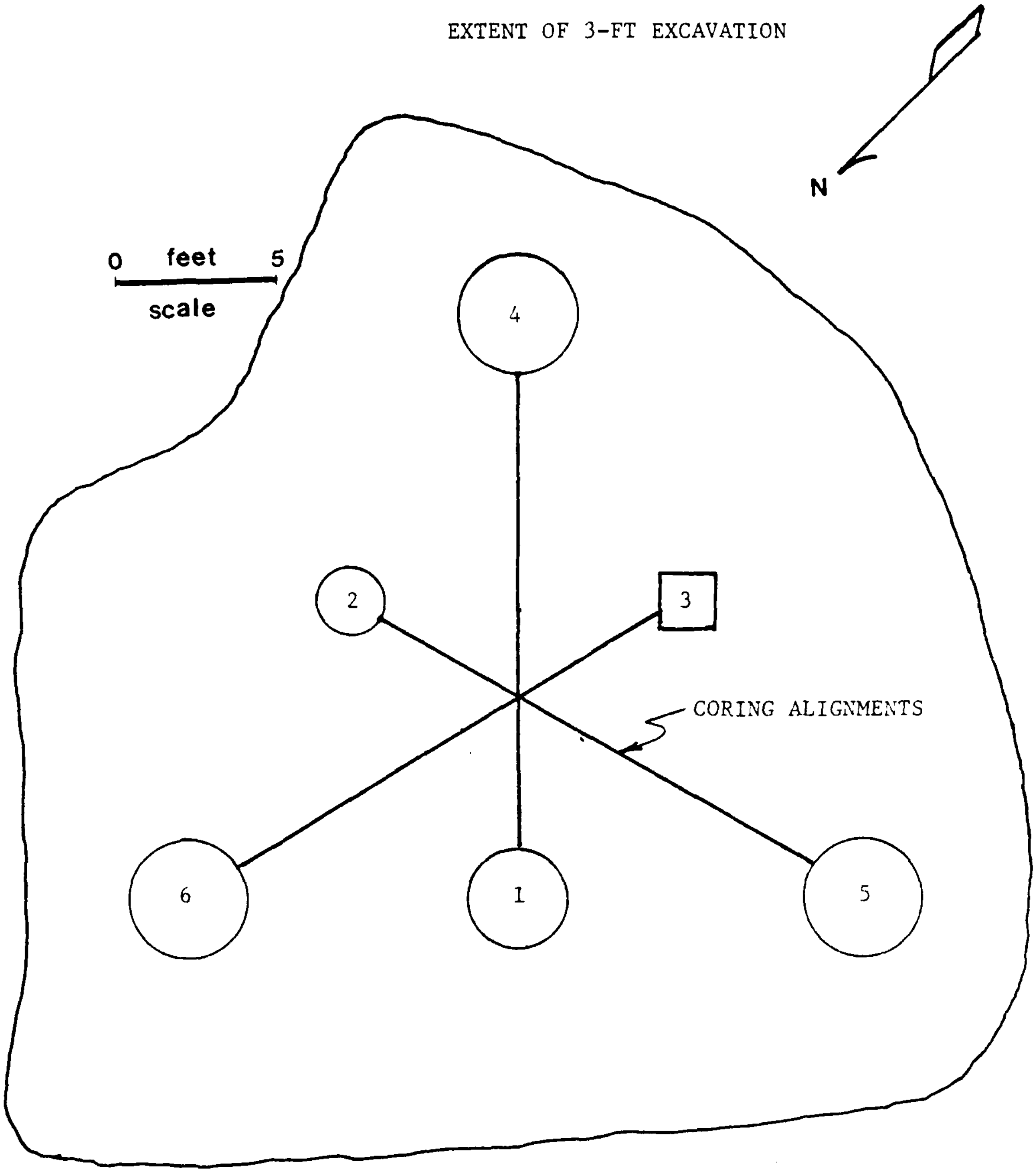
### 3.2 Geometry and Properties of the Piles

To accurately predict the response of laterally loaded piles, the geometry and flexural stiffness of the piles must be accurately represented. Correctly selecting the properties of the piles in this study was complicated since the piles had previously been stressed during the vertical load tests. The geometry and properties which were selected for use in the prediction process are presented in Table 1.

TABLE 1. Geometry and Properties of the Test Piles

| Pile ID Number | Description | Embedded Length (ft) | Assumed EI ($lb\text{-}in^2$) |
|---|---|---|---|
| 1 | 36" Diameter, Reinforced Concrete Drilled Shaft | 97 | $1.70 \times 10^{11}$ |
| 2 | 24" O.D., 5/8" Thick Steel Pipe Pile (Open-ended) | 10 | $0.91 \times 10^{11}$ |
| 3 | 20" Square Prestressed Concrete Pile | 98 | $0.16 \times 10^{11}$ |
| 4,5,6 | 42" Diameter, Reinforced Concrete Drilled Shaft | 128 | $1.80 \times 10^{11}$ |

The 36-in diameter drilled shaft was subjected to axial compression during the vertical load test. The flexural stiffness assumed for the lateral load test predictions was set equal to the stiffness obtained using its cracked moment of inertia. This method assumed that during lateral loading of the pile the portion of the pile cross section in compression transferred stresses to the concrete and to the




| PILE NO. | TYPE |
|---|---|
| 1 | 36" DIA. R.C. DRILLED SHAFT |
| 2 | 24" O.D. 5/8" THICK STEEL PIPE PILE |
| 3 | 20" SQUARE PRESTRESSED CONCRETE PILE |
| 4,5,6 | 42" DIA. R.C. DRILLED SHAFTS |

FIGURE 7. Arrangement and I.D. Numbers for the Test Piles

steel reinforcement. The portion of the cross section in tension, however, was assumed to carry all the stresses in the steel reinforcement alone. The areas of the cross section in compression and tension were assumed to be the compression and tension areas obtained when applying the allowable bending moment to the reinforced concrete section (Wang and Salmon, 1979). For a previously unstressed pile these assumptions may be considered to be conservative.

The 24-in pipe pile was assumed to have an elastic modulus of 29,000 ksi. The moment of inertia selected for the prediction process was based on the pile being completely empty of any soil throughout its length due to the soil plug being drilled out after driving.

For the 20-in square prestressed concrete pile, the stiffness calculation was further complicated by the fact the square cross section was not aligned with the direction of the horizontal load to be applied. The angle between the horizontal load and the sides of the square cross section was $26^{\circ}$. The selected stiffness in Table 1 considered the unusual angle of load application and was based on the cracked moment of inertia as explained for the 36-in drilled shaft. In all inertia computations, the prestressing strands were assumed to carry stresses only in tension, and were not included in the computations for the portion of the cross section in compression.

During the vertical load tests the three 42-in diameter reinforced concrete reaction shafts were subjected to axial tension up to 1000 tons. In the calculations of their flexural stiffness, the elastic modulus and the moment of inertia were substantially reduced from the values that would be assumed for a previously unstressed pile. This was necessary to account for the inevitable tension crack formation that must have occurred during the axial load tests.

## 4. THE LATERAL LOAD TESTS

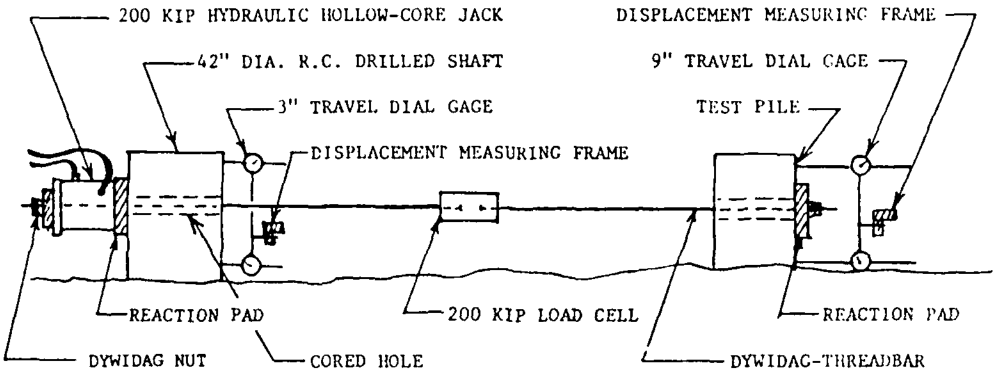
### 4.1 Site Preparation

The site had been backfilled following completion of the vertical load tests, necessitating excavation before performance of the lateral load tests. The boundaries of the excavation can be seen on the pile layout in Figure 7. The depth of the excavation was approximately 3 ft, allowing sufficient clearance for setting up the loading apparatus and the displacement gages support frame.

### 4.2 Loading Apparatus and Pile Preparation

The lateral loading of the piles was achieved using the system depicted in Figure 8. Each pile was cored horizontally to allow a length of 1-3/8 in, 150 ksi Dywidag-threadbar to be passed through the pile's central axis. The cored holes through each pile in the corner of the triangular layout were aligned with the cored holes through the pile on the opposite leg of the triangle (Figure 7). A length of threaded bar was passed through the cored hole of a corner pile and a 200-kip load cell was screwed onto the end of the bar near the center of the triangular layout. Another bar, passing through the pile on the opposite leg of the triangle, was screwed onto the other end of the load cell. Steel reaction pads were placed over the threaded bars behind the piles to distribute the lateral load over a wider area and the threaded bar was locked with a nut behind one of the two piles. A 200-kip hollow-core hydraulic jack was locked behind the opposite pile around the threaded bar. As the jack was expanded, the tensile force in the threaded bar pulled the two piles towards each other. The load cell measured the horizontal load applied to each pile.

Dial gages were securely attached to an independently supported displacement measuring frame. Deflections were measured at two points on each pile: one point below the




A = Distance from line of loading to top dial gage

B = Distance from line of loading to bottom dial gage

C = Distance from line of loading to ground surface

| Pile I.D. No. * | A (in.) | B (in.) | C (in.) |
|---|---|---|---|
| 1 | 24.75 | (4.25)** | 3.5 |
| 2 | 11.56 | 4.94 | 8.4 |
| 3 | 21.06 | 8.06 | 10.0 |
| 4 | 10.0 | 2.0 | 3.5 |
| 5 | 11.88 | 4.56 | 8.4 |
| 6 | 8.5 | 9.38 | 10.0 |

* See Figure 7.

** Above line of loading

FIGURE 8. Horizontal Load Application and Displacement Measuring System

axis of loading close to the groundline and one above the axis of loading. This allowed the deflection and the slope at the groundline to be obtained. The position of the displacement measuring frame was checked with a transit before and after each load test to guarantee that there was no movement of the frame during testing. The locations of the dial gages and the line of loading are shown on Figure 8.

**4.3 General Loading Scheme**

The loading scheme for each test followed the same general pattern. Loads were applied in five kip increments. After each increment, displacement readings were taken immediately and at one minute intervals for five minutes as the load was maintained. Two load levels were selected during each test to perform 20 unload-reload cycles. The cycles were performed under load-control conditions. After reaching the first chosen load level, the displacements were recorded during the first five minutes as the load was maintained. The load was then decreased to near zero by completely relaxing the jack. Displacements and load readings were recorded after two minutes and the original cyclic load level was reapplied. A new set of readings were then recorded after an additional two minutes; the cyclic period was thus four minutes. After ten cycles, the bottom, lower load, of each cycle was increased to half of the top cyclic load level. After twenty cummulative cycles, the five-kip, five-minute incremental loading was resumed. When the second chosen cyclic load level was reached, the load was cycled between the chosen load level and one-half of the chosen load level for the first ten cycles and then between the chosen load level and near zero load for the last ten cycles. After completion of the second series of cycles the five-kip, five-minute incremental loading was resumed and continued until the end of the test.

**4.4 Results of the Lateral Load Tests**

Tabulated results of the lateral load tests are pre-

sented in Appendix A. Lateral loads versus horizontal deflections of the piles are presented graphically in Figures 9 through 20. The displacements are those measured by the lowest dial gage for each pile, as described in Section 4.2. Two graphs are presented for each pile: one showing the entire response range during the load test and another detailing the cyclic response.

#### 4.4.1 Monotonic response envelopes

Curves enveloping the response of the piles to incremental loading intervals are presented as monotonic response envelopes in Figures 21 and 22. These curves yield a conservative estimate of each pile's behavior under strictly monotonic incremental loading. In reality, the responses for identical piles not subjected to the two series of cycles would likely be stiffer. This can be substantiated by observing the pronounced permanent displacements experienced by each pile during cyclic loading in the case where the load was decreased to almost zero load (Figures 9 through 20). Furthermore, the concrete piles were subjected to increased crack propagation during the cyclic series (see Section 6) effectively reducing their stiffness as the tests progressed.

The monotonic response envelopes allow comparisons between the piles to be made. The three 42-in diameter drilled shafts reponded within a narrow range of values, showing consistency within the testing method, shaft construction and soil properties. They proved to have the stiffest response, followed by the 36-in diameter drilled shaft, the 24-in diameter steel pipe pile and finally the 20-in square prestressed concrete pile.

One of the 42-in diameter drilled shafts failed during the load tests (Pile No. 6). This premature failure reflects the damage incurred by the reaction shafts during the vertical load tests discussed in Section 3.

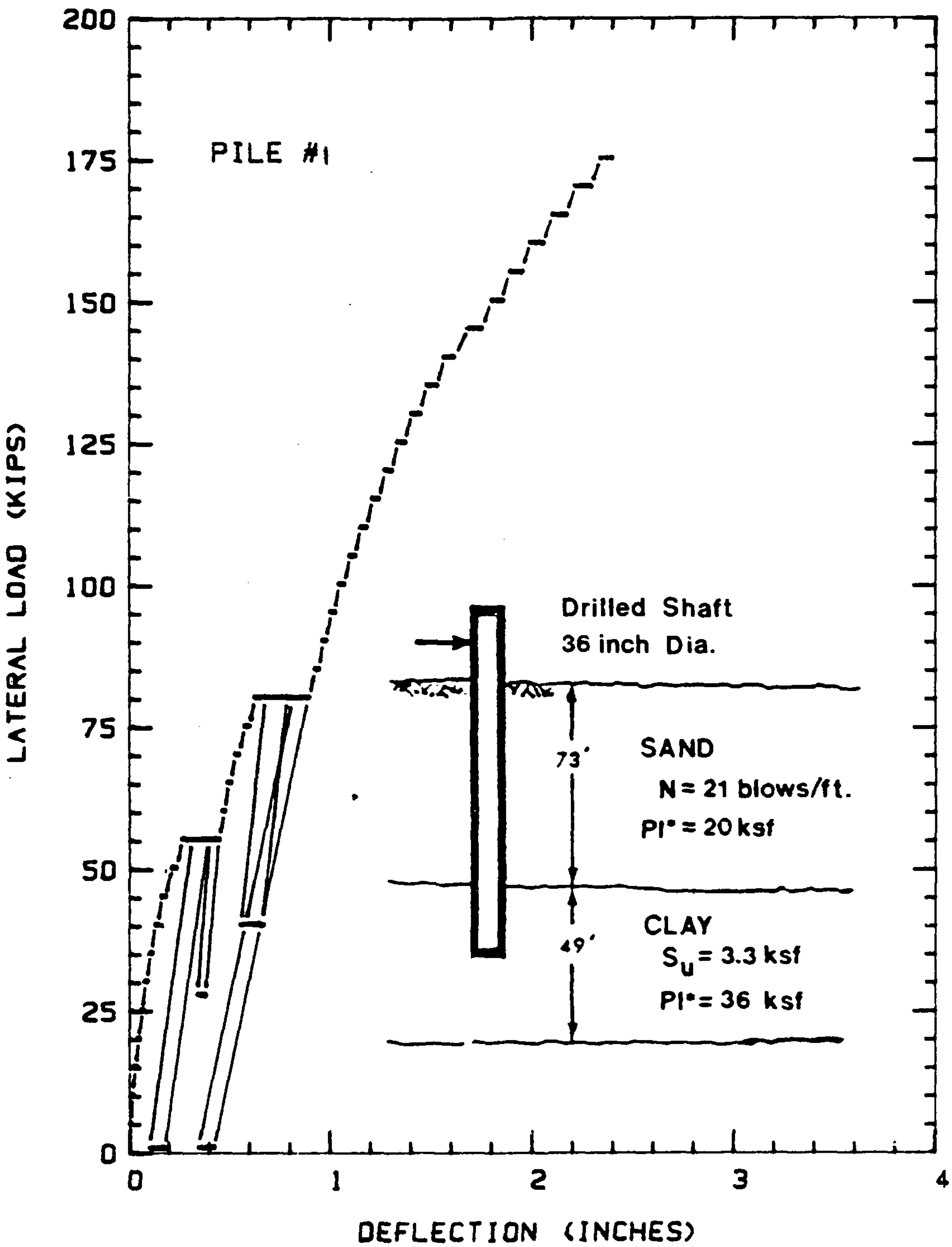



FIGURE 9. Measured Response from Cyclic Lateral Load Test for Pile No. 1, 0 to 200 Kips Scale.

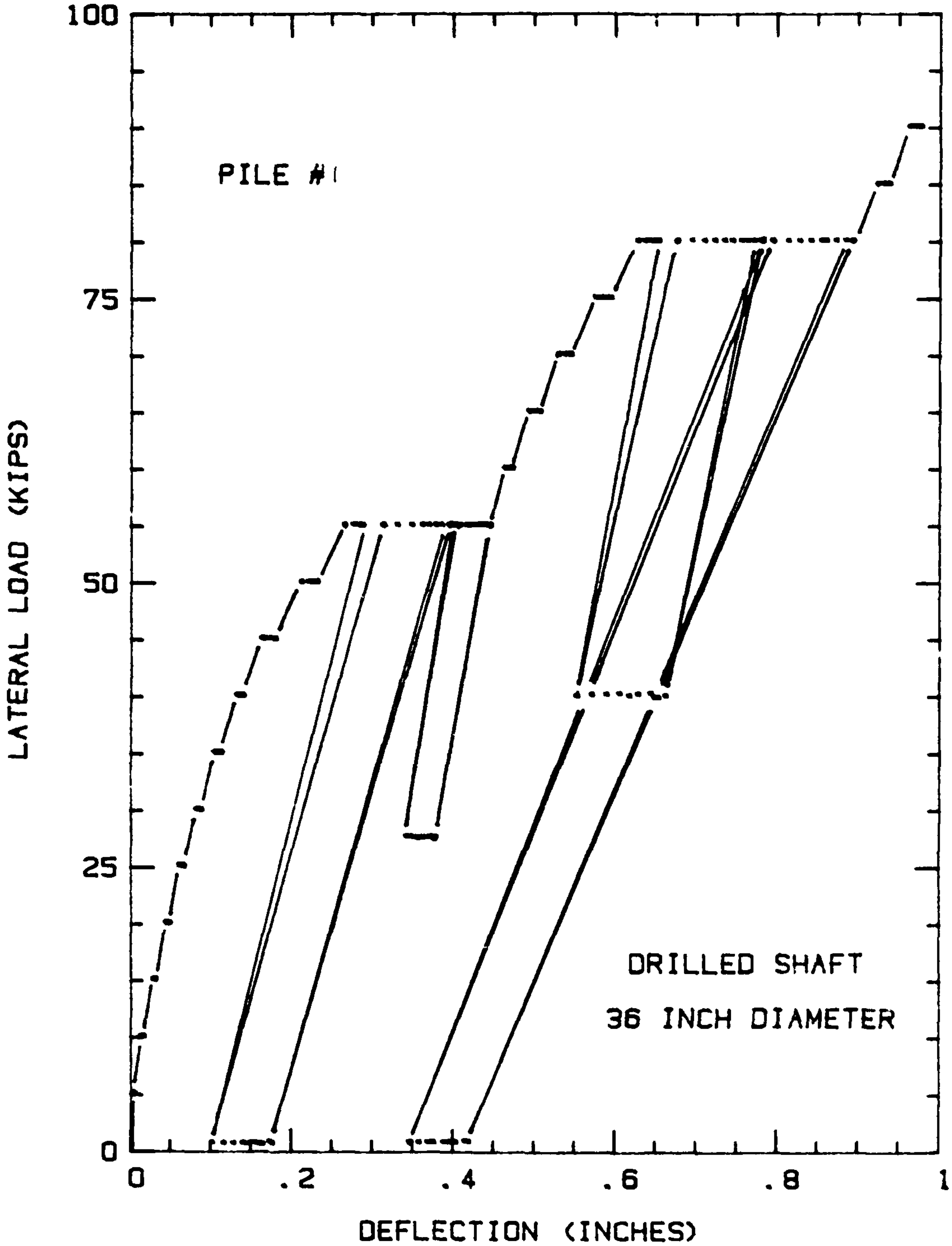



FIGURE 10. Measured Response from Cyclic Lateral Load Test for Pile No. 1, Cycling Detail, 0 to 100 Kips Scale.

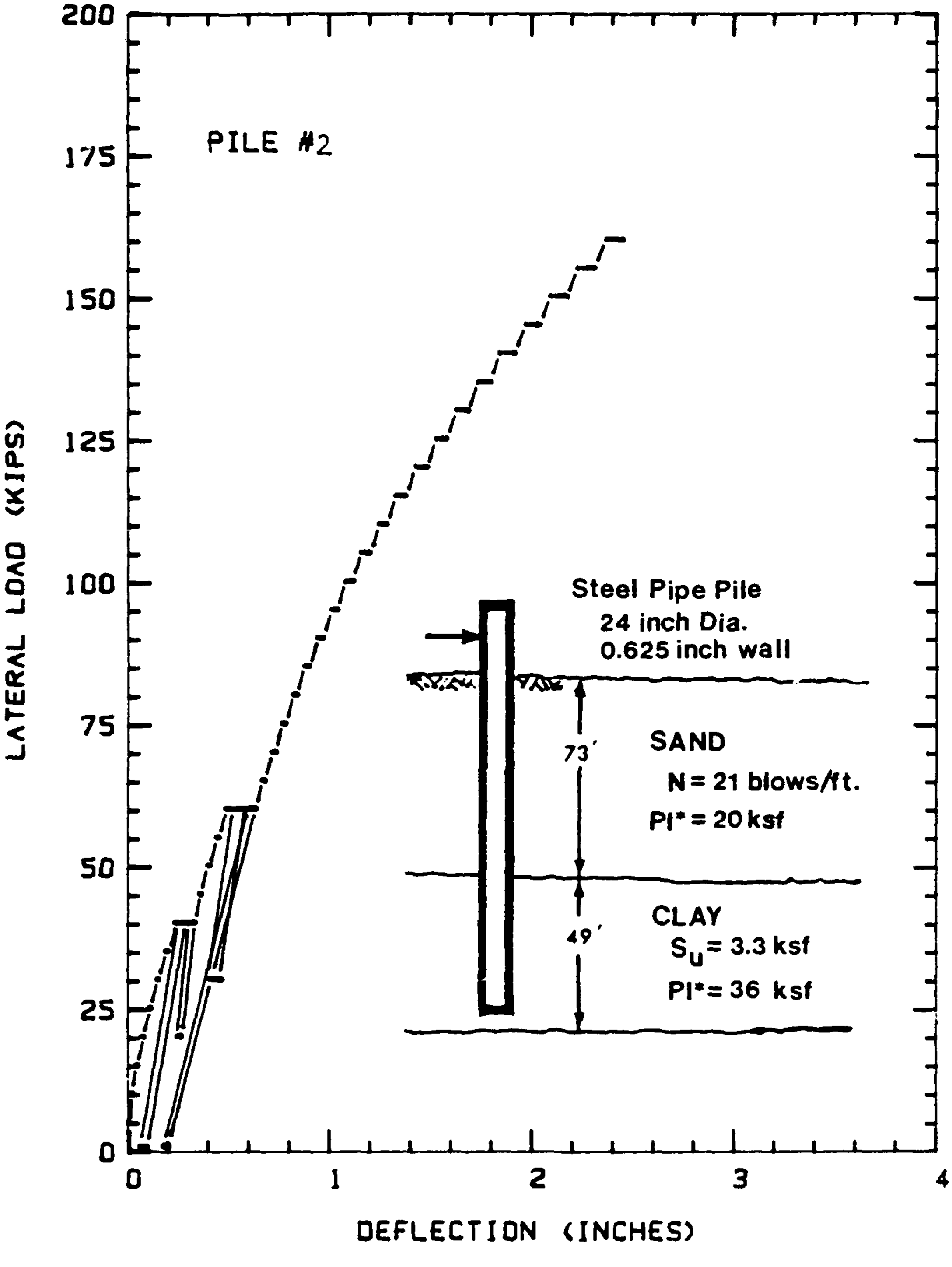



FIGURE 11. Measured Response from Cyclic Lateral Load Test for Pile No. 2, 0 to 200 Kips Scale.

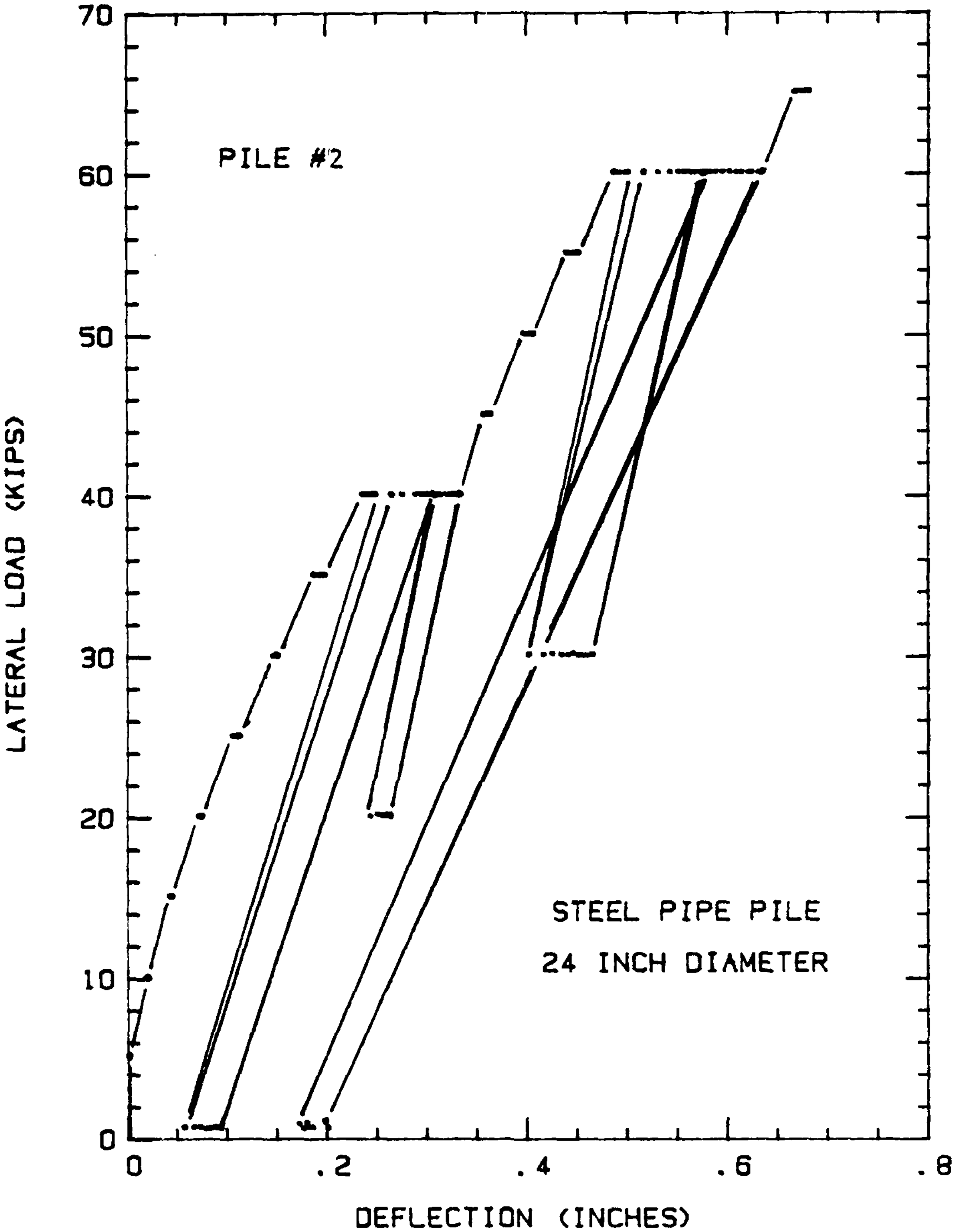



FIGURE 12. Measured Response from Cyclic Lateral Load Test for Pile No. 2, Cycling Detail, 0 to 70 Kips Scale.

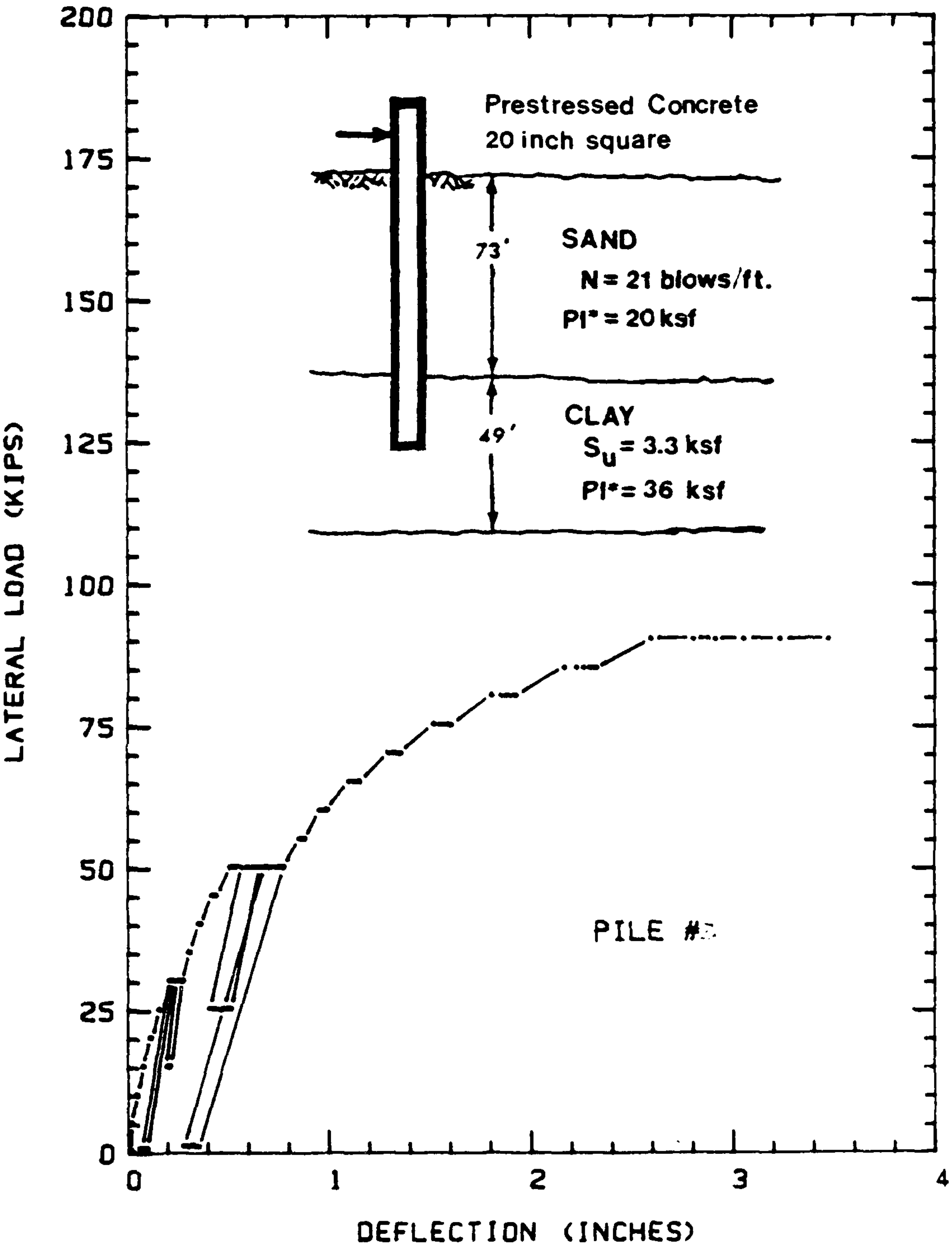



FIGURE 13. Measured Response from Cyclic Lateral Load Test for Pile No. 3, 0 to 200 Kips Scale.

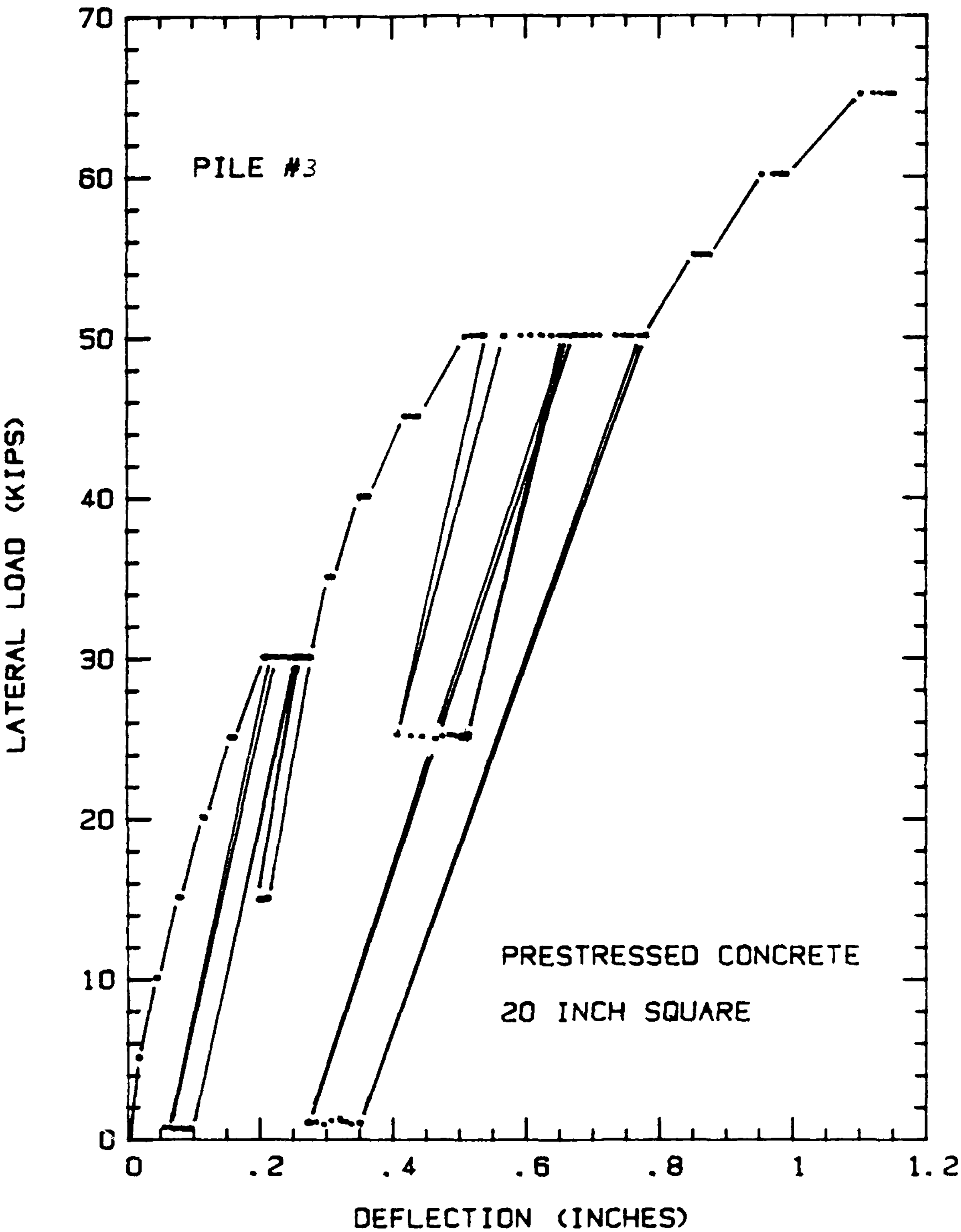



FIGURE 14. Measured Response from Cyclic Lateral Load Test for Pile No. 3, Cyclcing Detail, 0 to 70 Kips Scale.

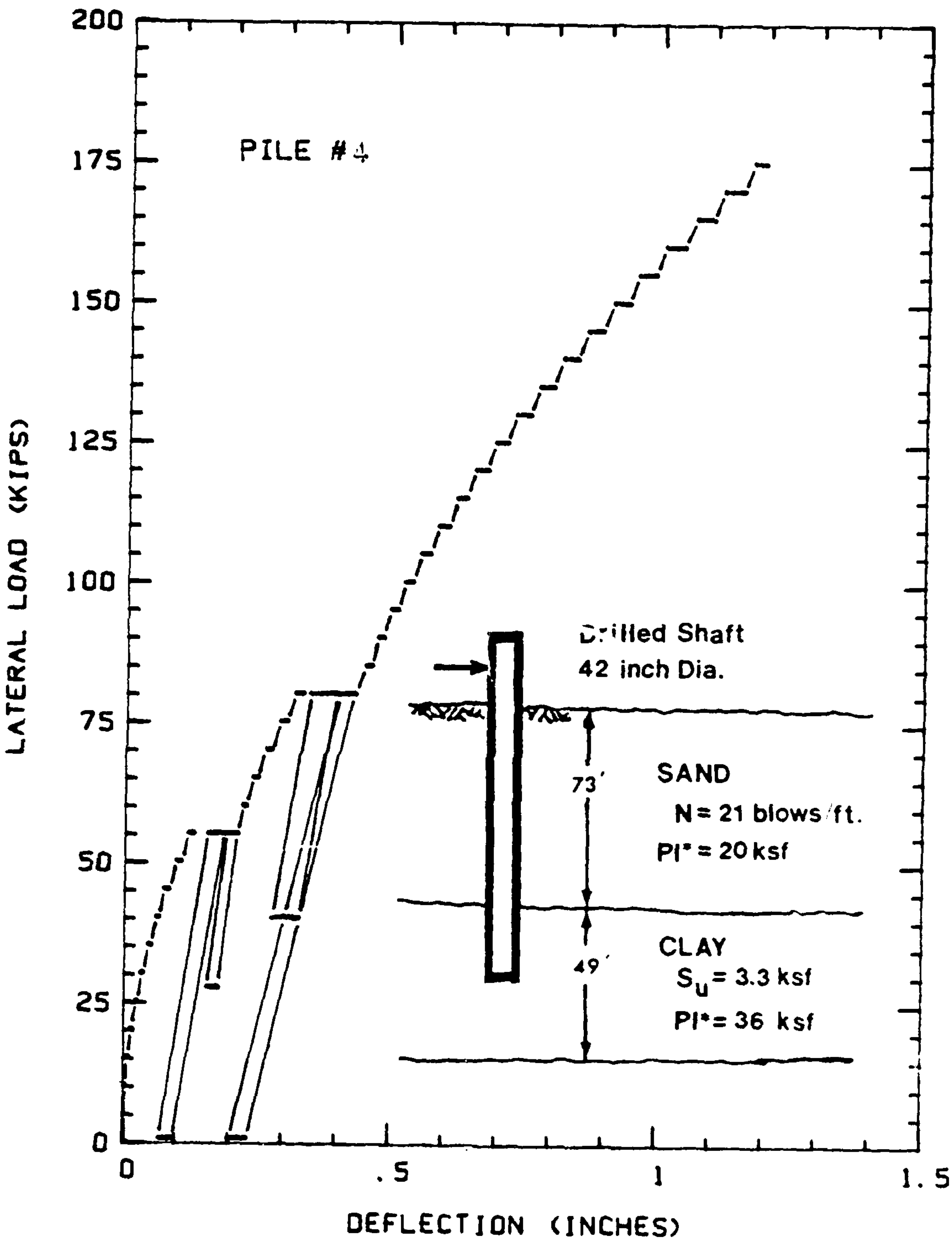



FIGURE 15. Measured Response from Cyclic Lateral Load Test for Pile No. 4, 0 to 200 Kips Scale.

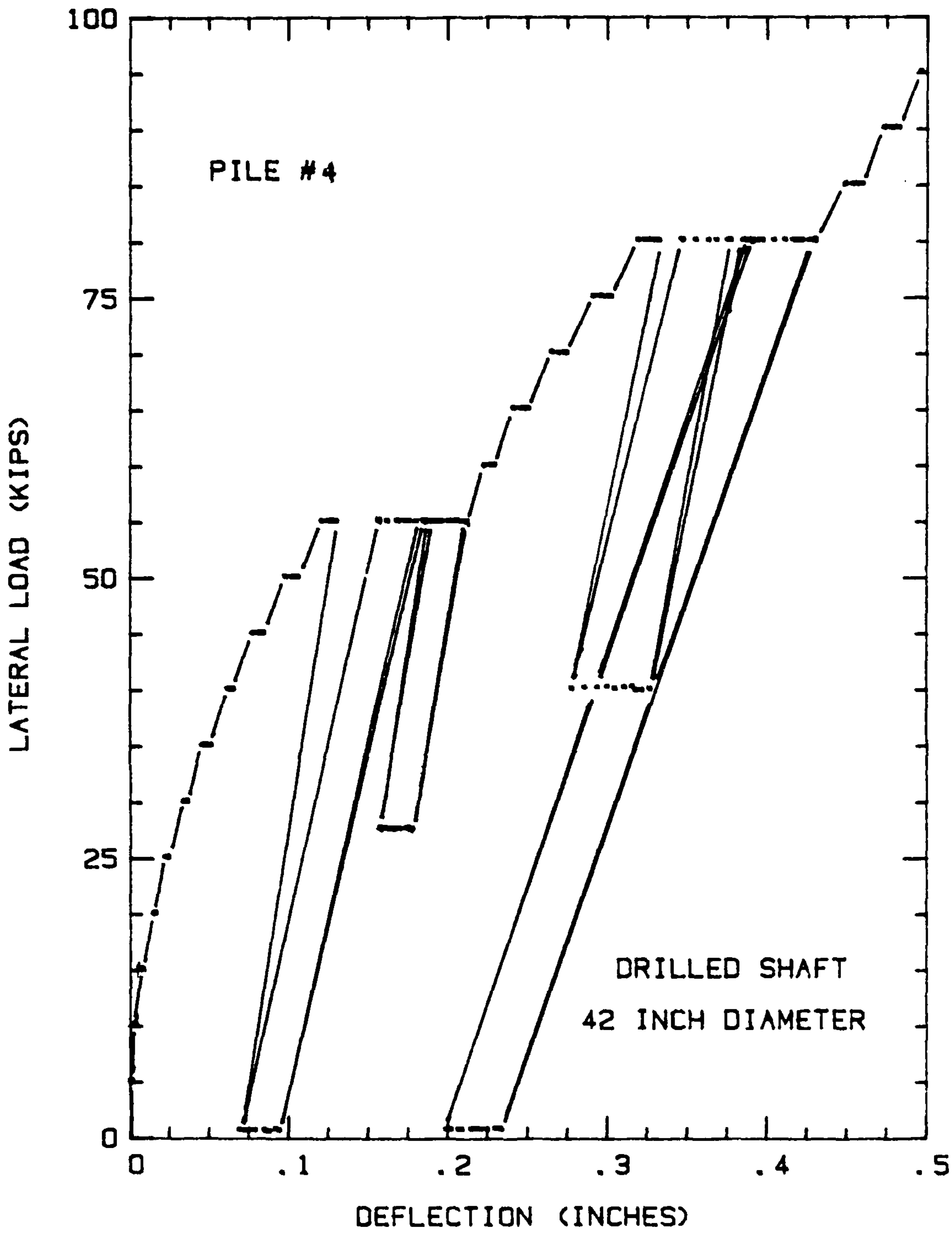



FIGURE 16. Measured Response from Cyclic Lateral Load Test for Pile No. 4, Cycling Detail, 0 to 100 Kips Scale.

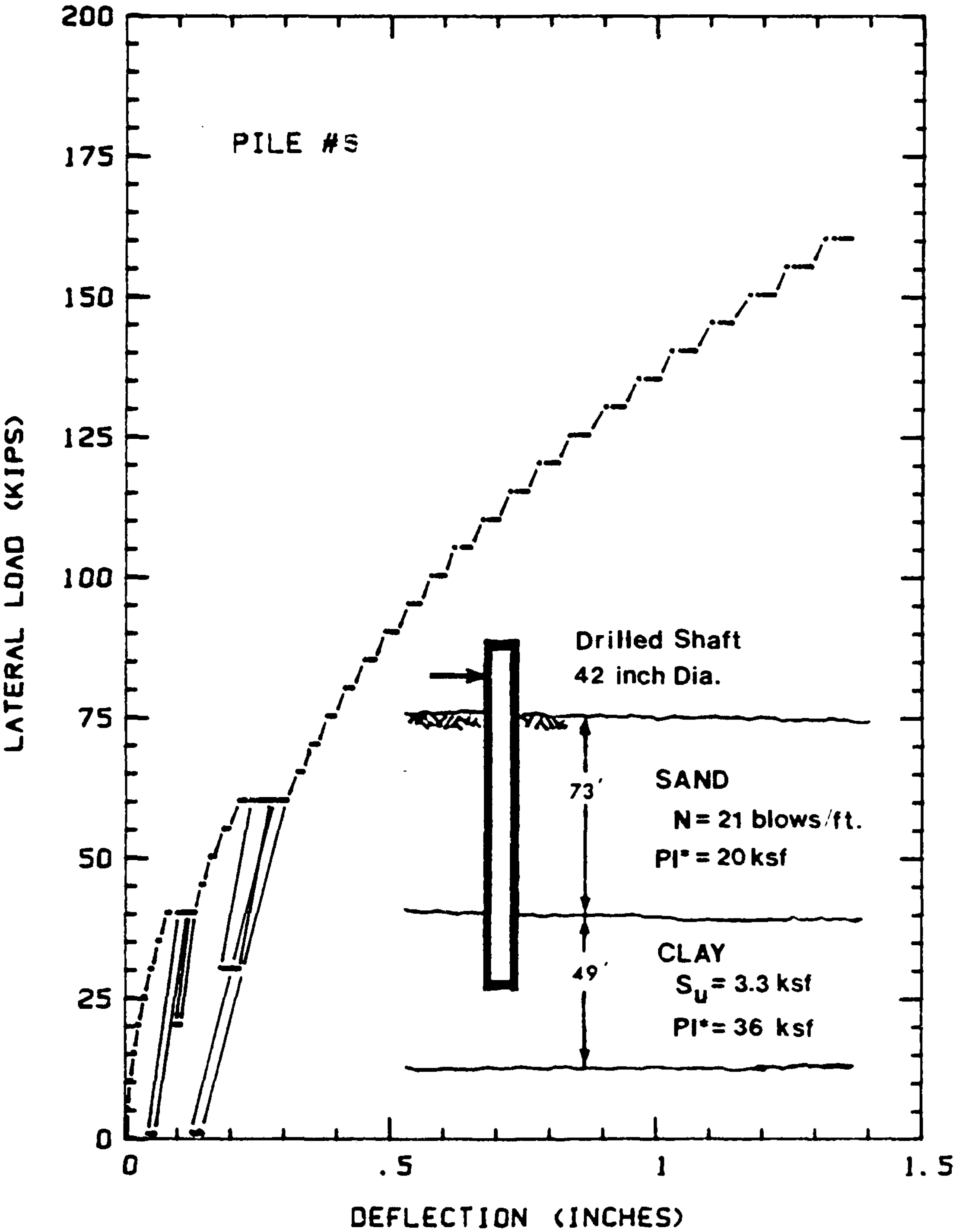



FIGURE 17. Measured Response from Cyclic Lateral Load Test for Pile No. 5, 0 to 200 Kips Scale.

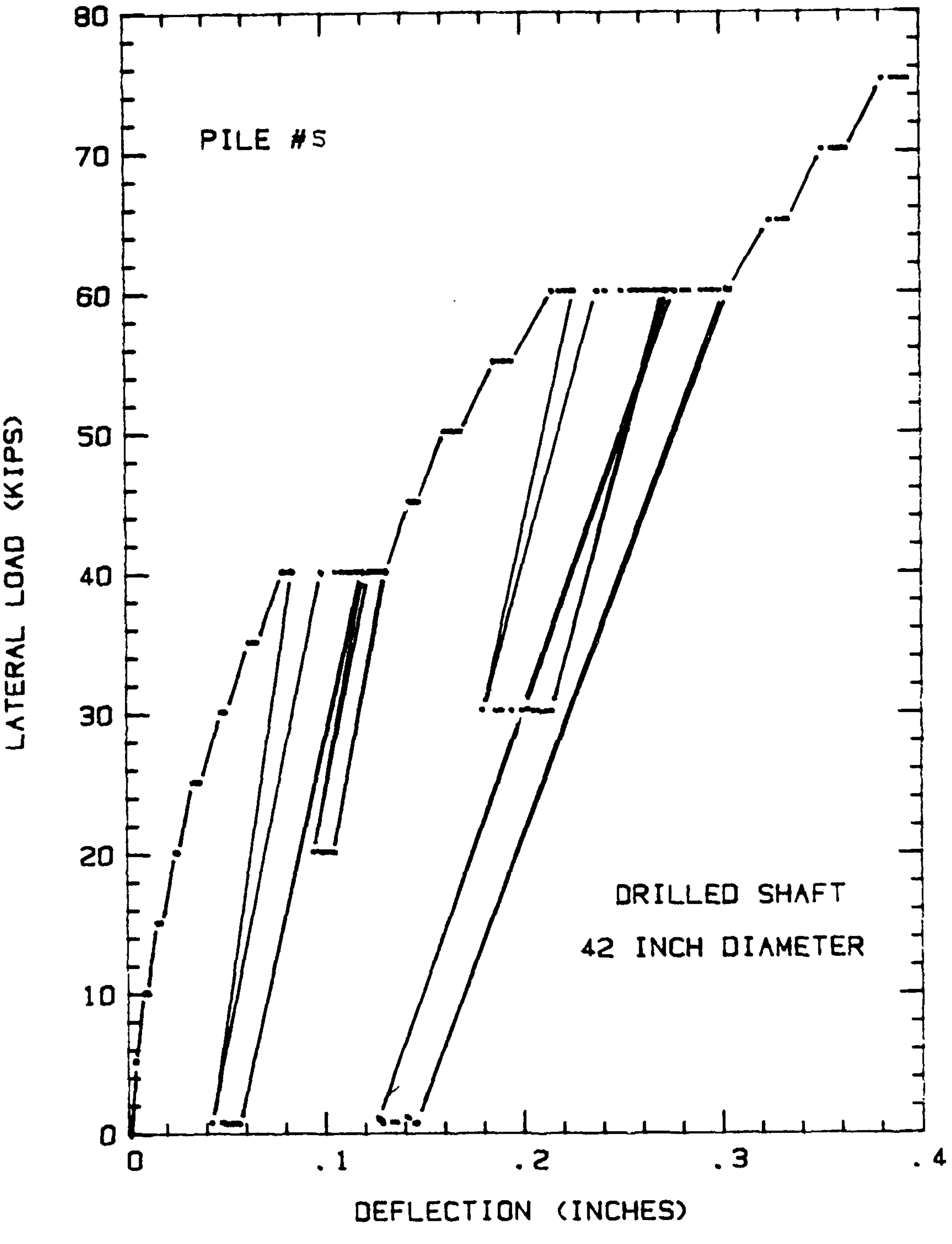



FIGURE 18. Measured Response from Cyclic Lateral Load Test for Pile No. 5, Cycling Detail, 0 to 80 Kips Scale.

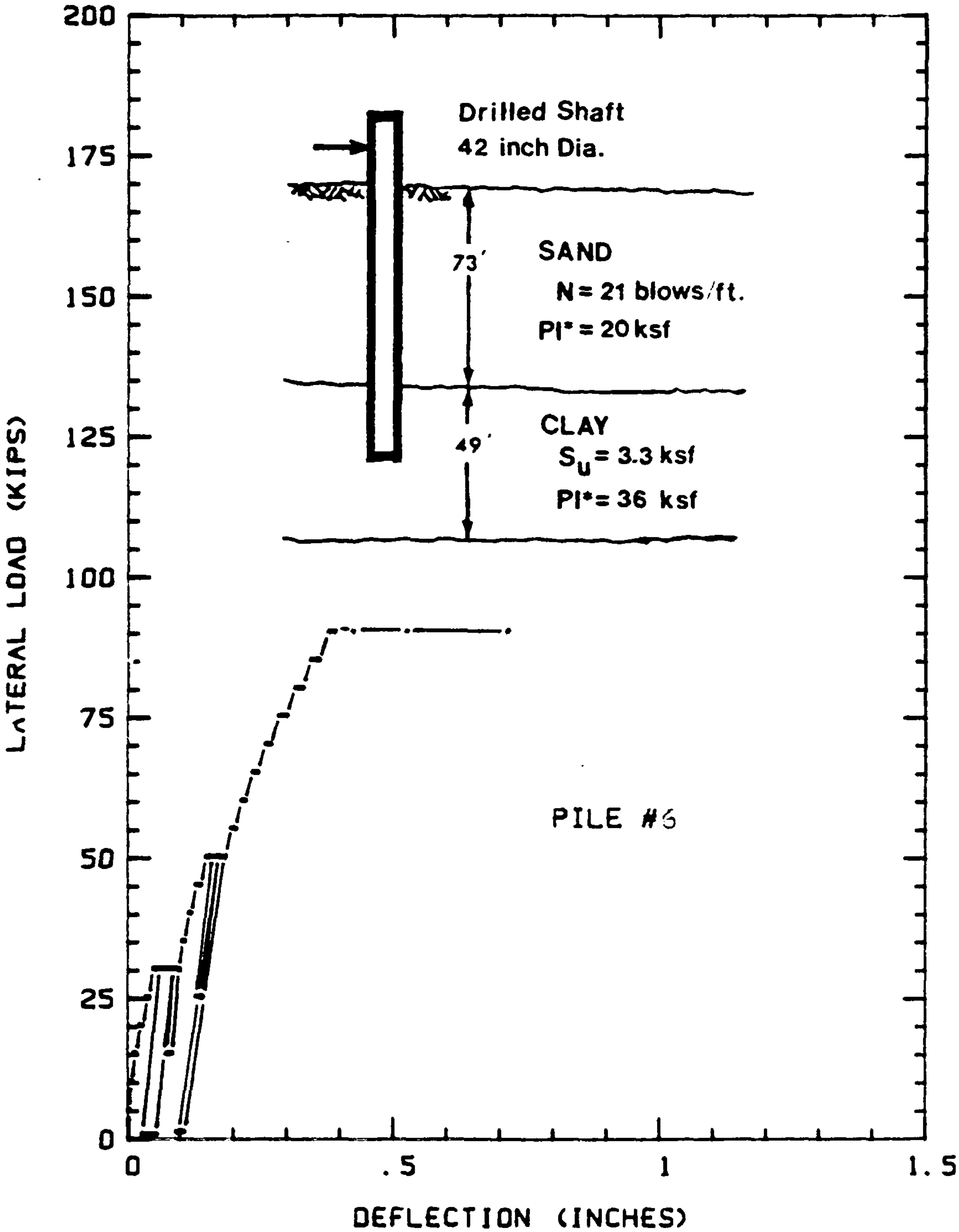



FIGURE 19. Measured Response from Cyclic Lateral Load Test for Pile No. 6, 0 to 200 Kips Scale.

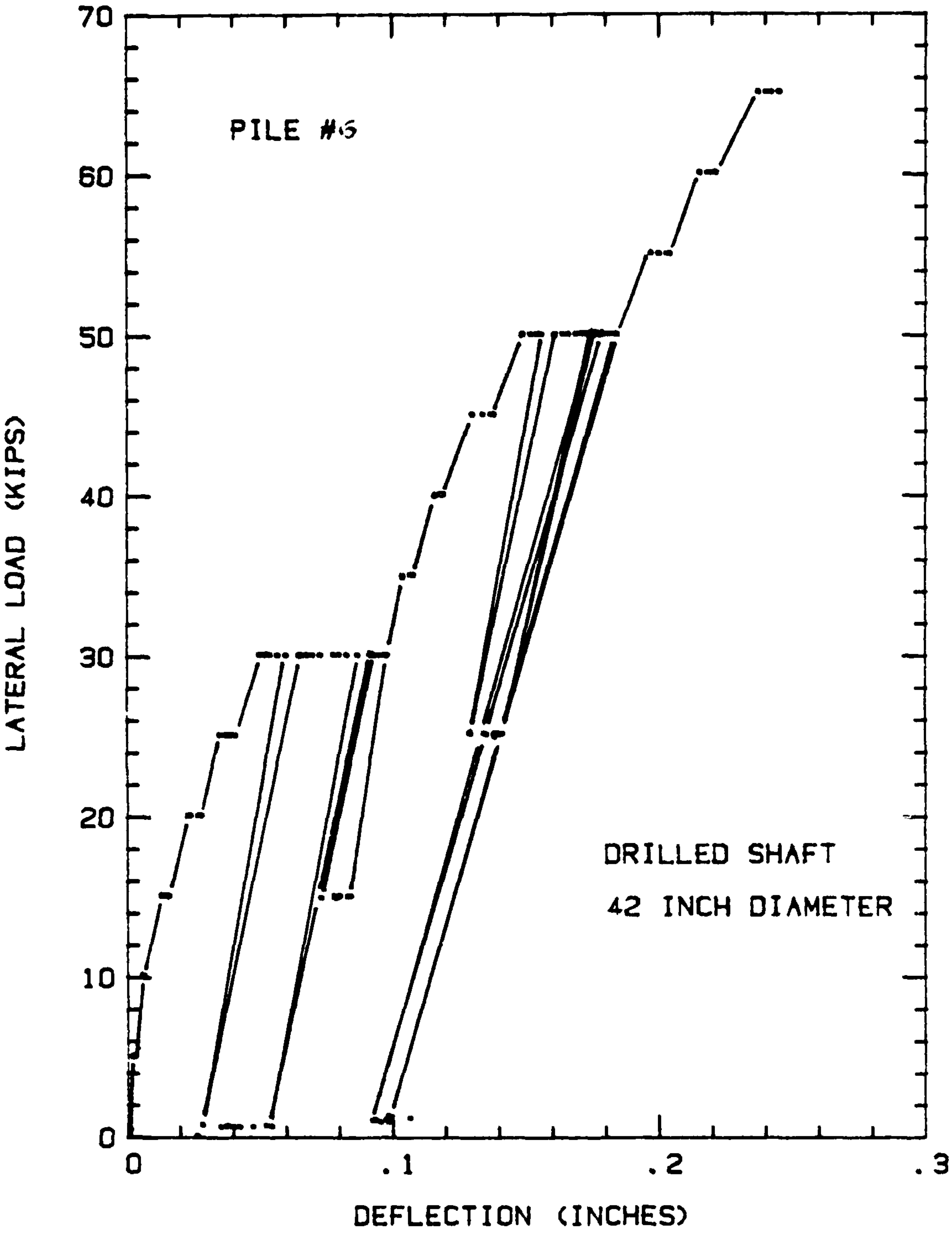



FIGURE 20. Measured Response from Cyclic Lateral Load Test for Pile No. 6, Cycling Detail, 0 to 70 Kips Scale.

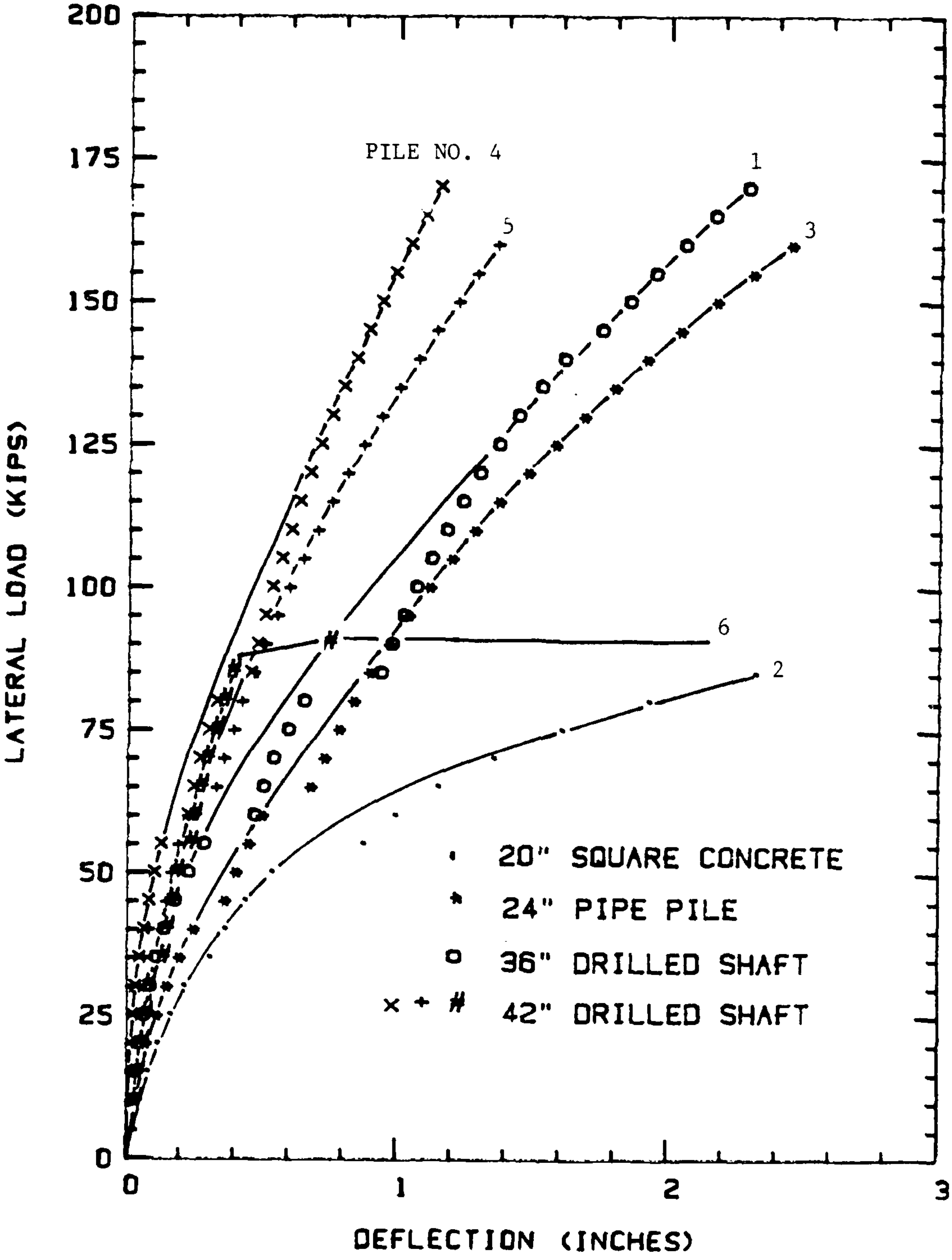



FIGURE 21. Monotonic Response Envelopes Measured During Pile Load Tests, Full Range Scale.

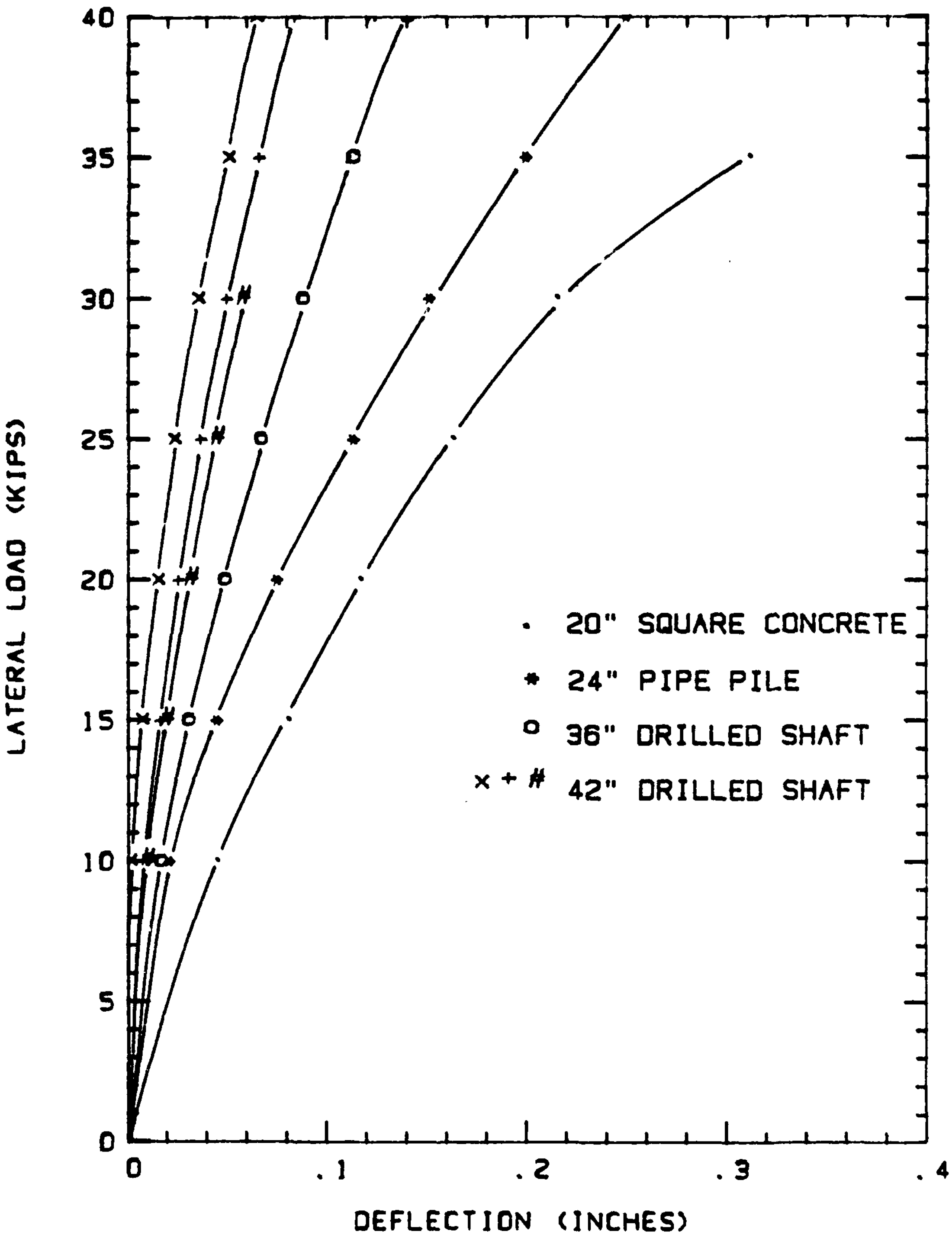



FIGURE 22. Monotonic Response Envelopes Measured During Pile Load Tests, 0 to 40 Kips Scale.

### 4.4.2 Cyclic response and degradation

The cyclic response of the piles is presented in two different ways: 1. as percentage increase in displacement after cyclic loading, and 2. in terms of cyclic degradation of the secant and cyclic shear stiffnesses.

The percentage increase in displacement was measured as shown in Figure 23. Table 2 lists the increase in displacement after 10 and 20 cycles for each pile at each cyclic load level. Several observations concerning the pile's responses may be made from the tabulation.

TABLE 2. Measured Cyclic Percentage Increase in Displacement from the Pile Load Tests

| Pile ID No. | Description | First Cycling Level | | | Second Cycling Level | | |
|---|---|---|---|---|---|---|---|
| | | Load (kips) | % Increase in Displacement @ 10 cycles | % Increase in Displacement @ 20 cycles | Load (kips) | % Increase in Displacement @ 10 cycles | % Increase in Displacement @ 20 cycles |
| 1 | 36" Drilled Shaft | 55 | 51.1 | 66.9 | 80 | 17.9 | 35.4 |
| 2 | 24" Pipe Pile | 40 | 24.9 | 34.1 | 60 | 15.2 | 25.9 |
| 3 | 20" Square Concrete | 30 | 22.3 | 27.9 | 50 | 26.4 | 43.1 |
| 4 | 42" Drilled Shaft | 55 | 55.4 | 72.7 | 80 | 17.8 | 28.3 |
| 5 | 42" Drilled Shaft | 40 | 41.7 | 56.0 | 60 | 19.5 | 34.1 |
| 6 | 42" Drilled Shaft | 30 | 48.1 | 79.6 | 50 | 11.5 | 17.9 |

The four reinforced concrete drilled shafts suffered significantly more loss in pile-soil stiffness during the first cyclic series than the steel pipe or prestressed concrete pile. This greater loss probably reflects the rapid deterioration in the piles' flexural stiffness as the concrete experiences crack propagation, and the more compressible soil left by the drilling process at the concrete/soil interface. At the second, higher, cyclic load level, the relative increase in displacements with increasing number of

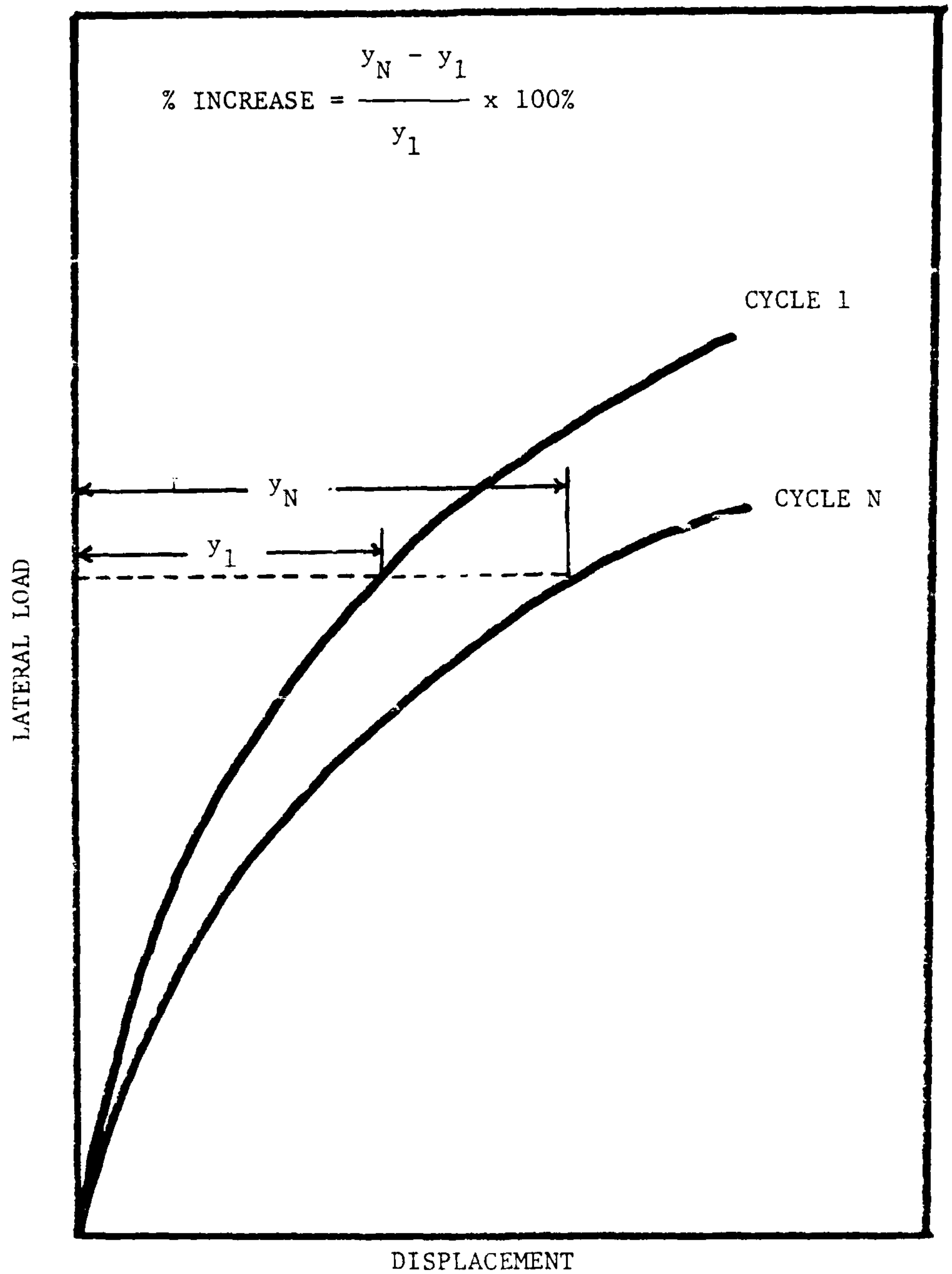



FIGURE 23. Percentage Increase in Displacement Calculation.

cycles was much lower. This difference may be explained as follows. During the first series of cycles the piles' flexural stiffness deterioration contributed significantly to the total pile-soil stiffness response. In the second cyclic series, as the piles' flexural stiffness was reaching a limiting value and since the sand had been stiffened by the first series of cycles, the cyclic deterioration of the pile-soil stiffness was much less. As an example, notice that pile 4 was cycled at 55 kips and experienced an increase in displacement of 72.7% after 20 cycles, whereas pile 6 cycled at 50 kips experienced only a 17.9% increase in displacement. The significant difference was that the 55 kips cycling level was the first cyclic series for pile 4 and the 50 kips cycling level was the second cyclic series experienced by pile 6, occurring after a cyclic series at a load level of 30 kips.

The prestressed 20-in square concrete pile and the steel pipe pile did not exhibit the same behavior. Prestressing of the square concrete pile enabled it to resist the effects of crack propagation by keeping a larger portion of the pile cross-section in compression during the lateral loading. As a result, the percentage increase in displacements of the prestressed concrete pile duplicate more closely the behavior of the steel pipe pile during the first series of cycles. At the second cyclic load level, the prestressed concrete pile showed a significant increase in relative displacement during the last ten cycles. At this load level, the internal bending moment within the pile was probably of sufficient magnitude to put a large portion of the concrete cross-section into tension, causing crack propagation and the associated loss in pile stiffness.

Very little loss in pile stiffness alone was expected in the 24-in diameter steel pipe pile load test, especially at low load levels. It is reasonable to assume then, that

the majority of the relative increase in displacement due to cyclic loading is the result of the soil stiffness degradation. This assumption seems to be reinforced when comparing the response of the 24-in diameter pipe at the 60-kip load level with the response of the drilled shafts during the second series of cycles. Indeed, all the values are relatively close to one another.

Another method used to evaluate the effect of cyclic loading on the pile-soil stiffness was to evaluate the degradation of the piles secant stiffness $K_{S(N)}$ as described in Figure 24. The cyclic degradation parameter "a" is defined as the negative slope of the best fit line through the points plotted on the graph of the relative secant stiffness $K_{S(N)}/K_{S(1)}$, versus the cycle number, N, on a log-log scale (Figure 24). The "a" values obtained from the pile load tests are presented in Table 3. The actual relative secant stiffness degradation plots are presented in Figures 25 through 30.

TABLE 3. Measured Secant Shear Modulus Degradation Parameters

| Pile ID No. | Description | Top Cyclic Load, H (kips) | "a" Values | | | | |
|---|---|---|---|---|---|---|---|
| | | | Reload @ H/2 | Reload near 0 | Average 1st Level | Average 2nd Level | Overall Average |
| 1 | 36" Drilled Shaft | 55 | 0.064 | 0.098 | 0.091 | | 0.086 |
| | | 80 | 0.046 | 0.136 | | 0.081 | |
| 2 | 24" Pipe Pile | 40 | 0.069 | 0.061 | 0.065 | | 0.062 |
| | | 60 | 0.038 | 0.081 | | 0.059 | |
| 3 | 20" Square Concrete | 30 | 0.031 | 0.045 | 0.038 | | 0.063 |
| | | 50 | 0.067 | 0.109 | | 0.088 | |
| 4 | 42" Drilled Shaft | 55 | 0.095 | 0.090 | 0.093 | | 0.080 |
| | | 80 | 0.044 | 0.091 | | 0.068 | |
| 5 | 42" Drilled Shaft | 40 | 0.066 | 0.080 | 0.073 | | 0.073 |
| | | 60 | 0.049 | 0.096 | | 0.073 | |
| 6 | 42" Drilled Shaft | 30 | 0.082 | 0.092 | 0.087 | | 0.068 |
| | | 50 | 0.030 | 0.068 | | 0.049 | |
| | Averages | | 0.057 | 0.087 | 0.075 | 0.070 | 0.072 |

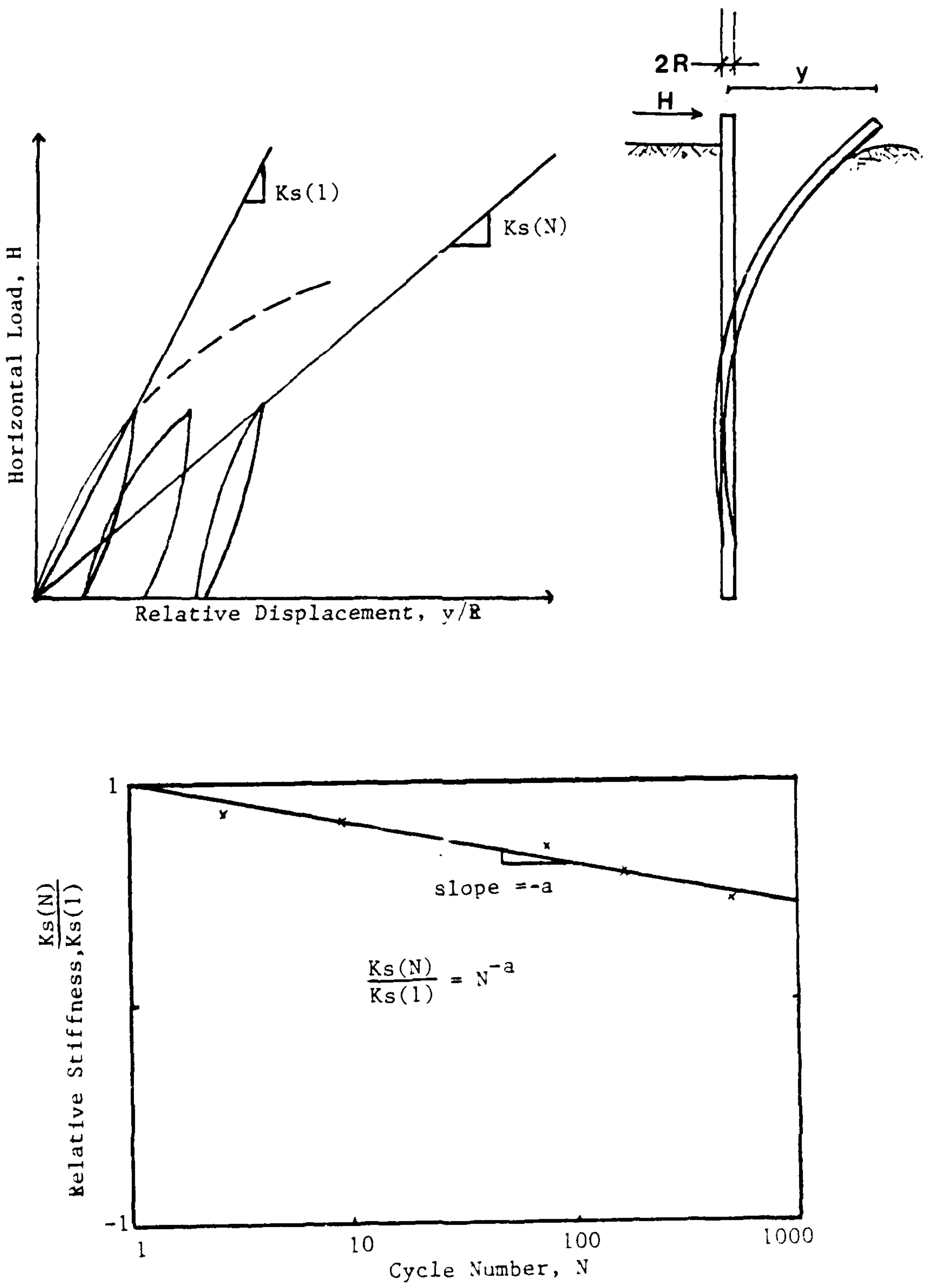



FIGURE 24. Cyclic Parameters Definition (After Makarim and Briaud, 1986).

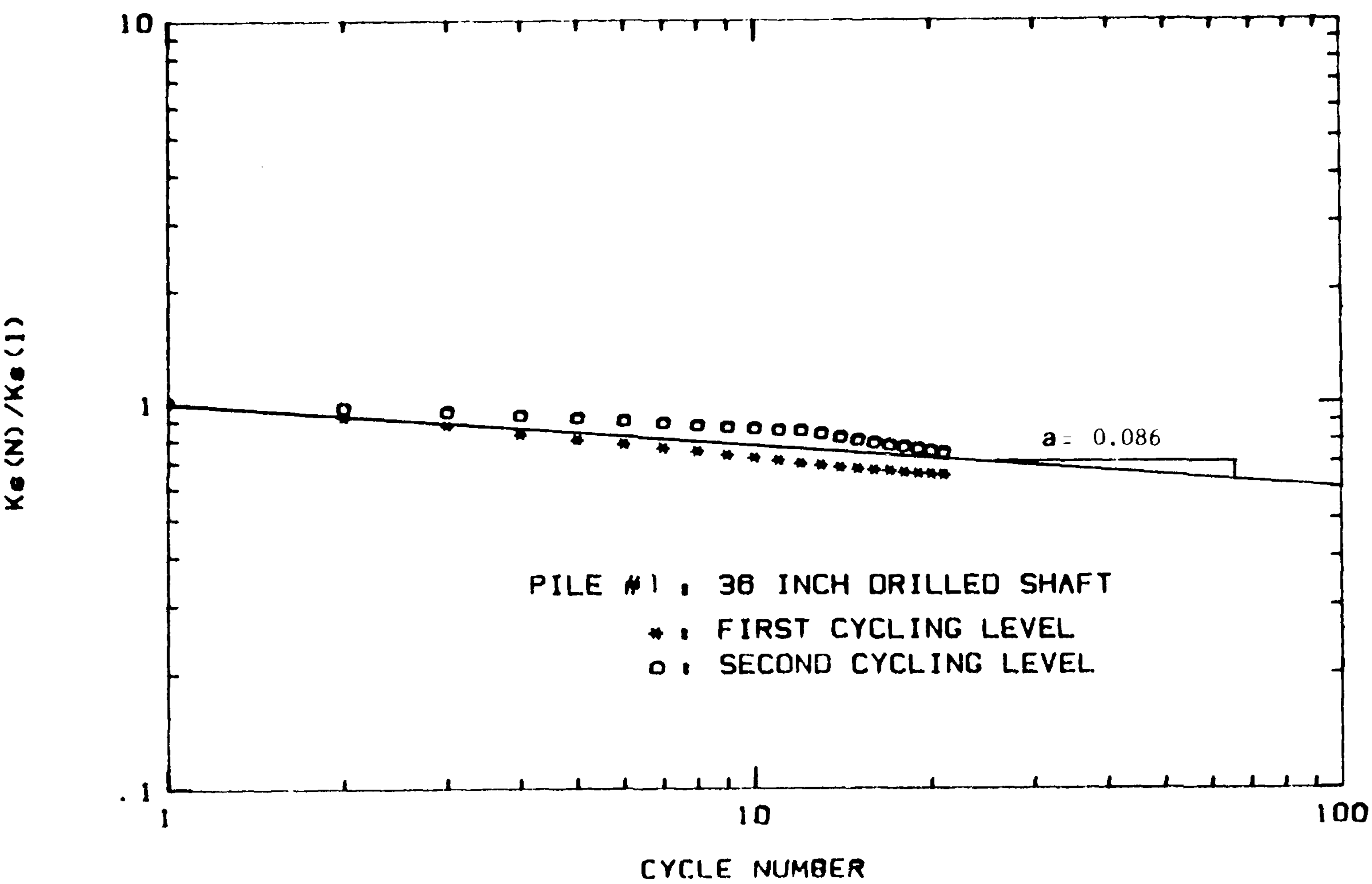



FIGURE 25. Measured Secant Shear Modulus Degradation for Pile No. 1.

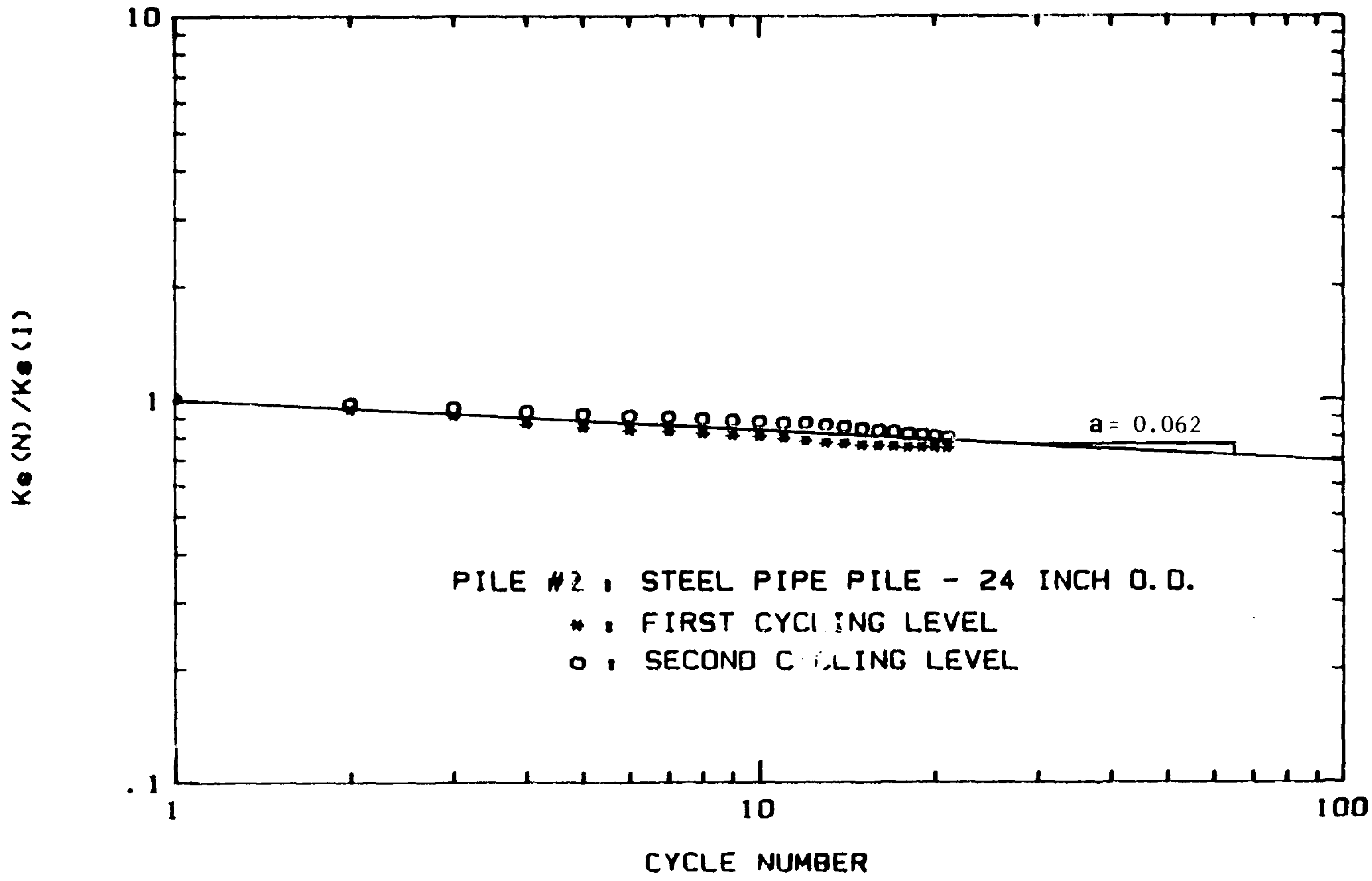



FIGURE 26. Measured Secant Shear Modulus Degradation for Pile No. 2.

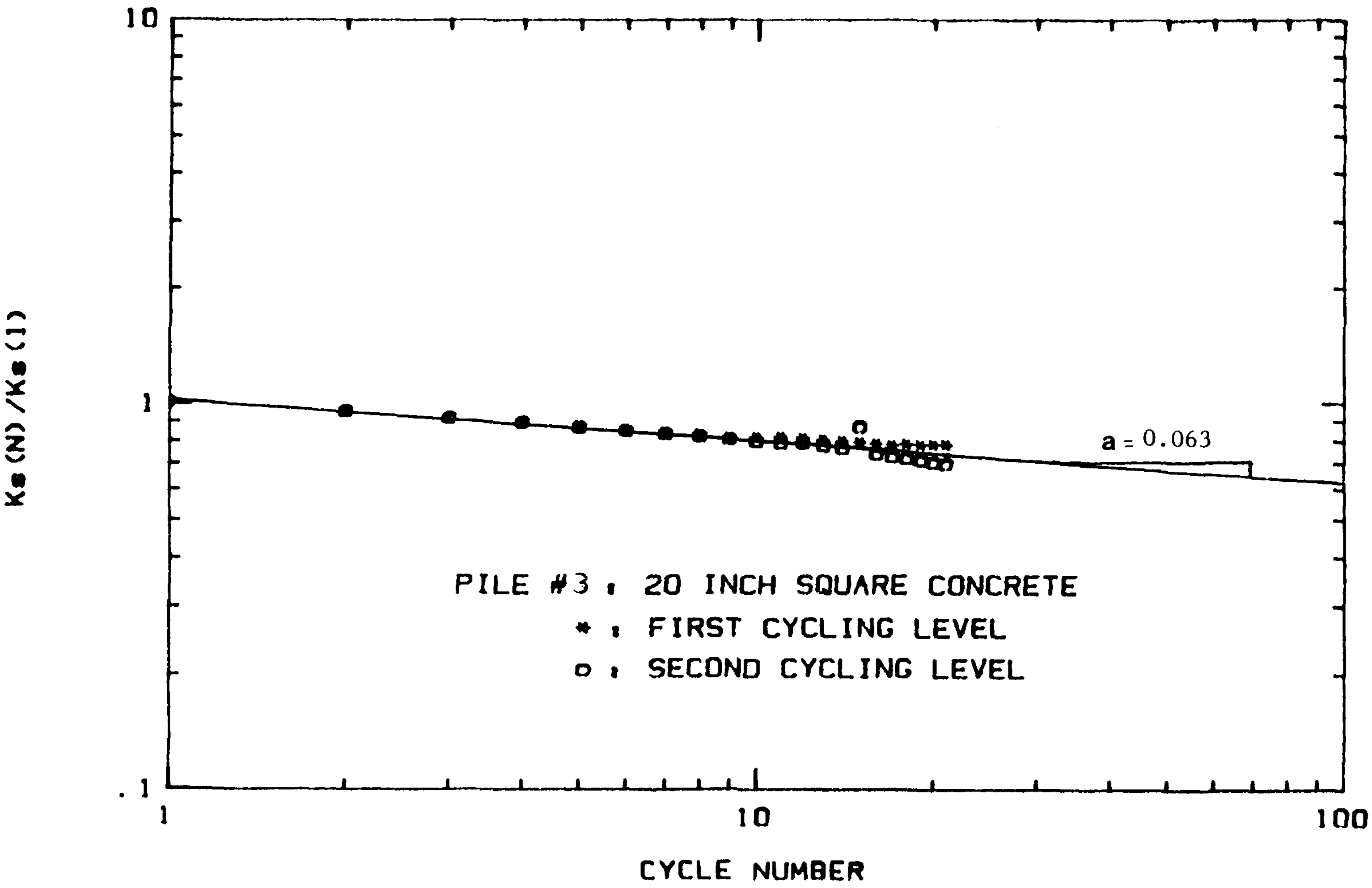



FIGURE 27. Measured Secant Shear Modulus Degradation for Pile No. 3.

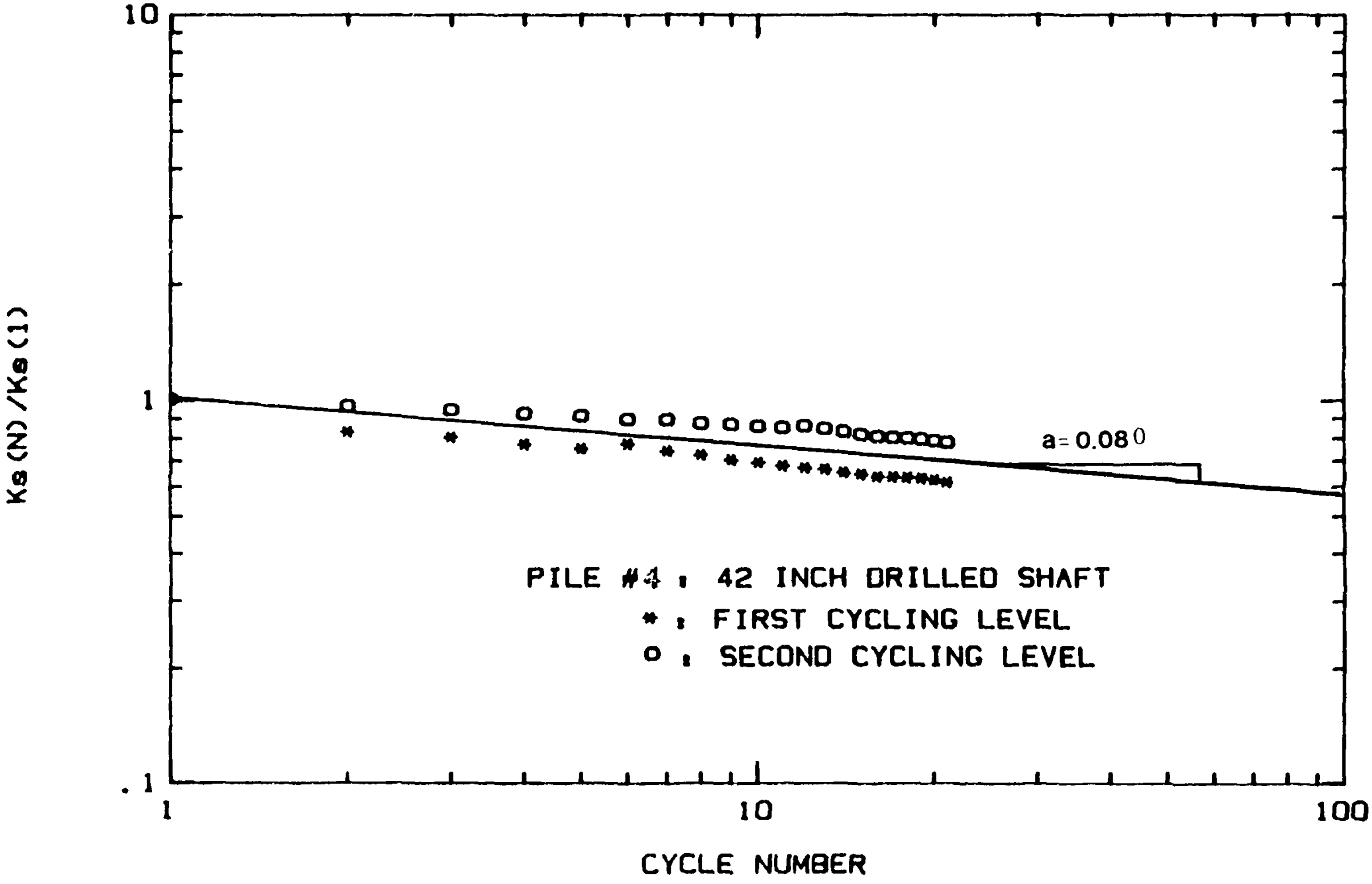



FIGURE 28. Measured Secant Shear Modulus Degradation for Pile No. 4.

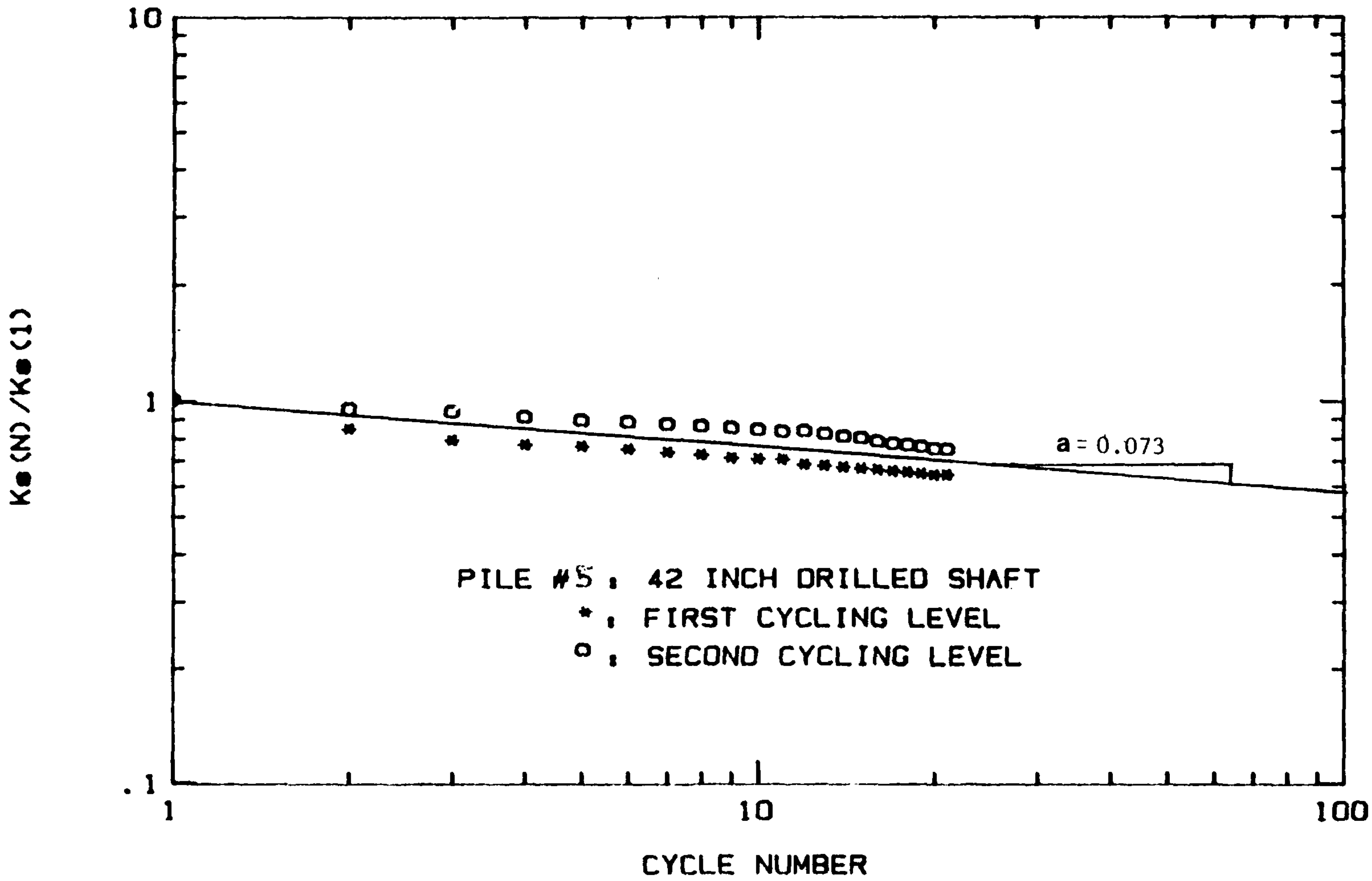



FIGURE 29. Measured Secant Shear Modulus Degradation for Pile No. 5.

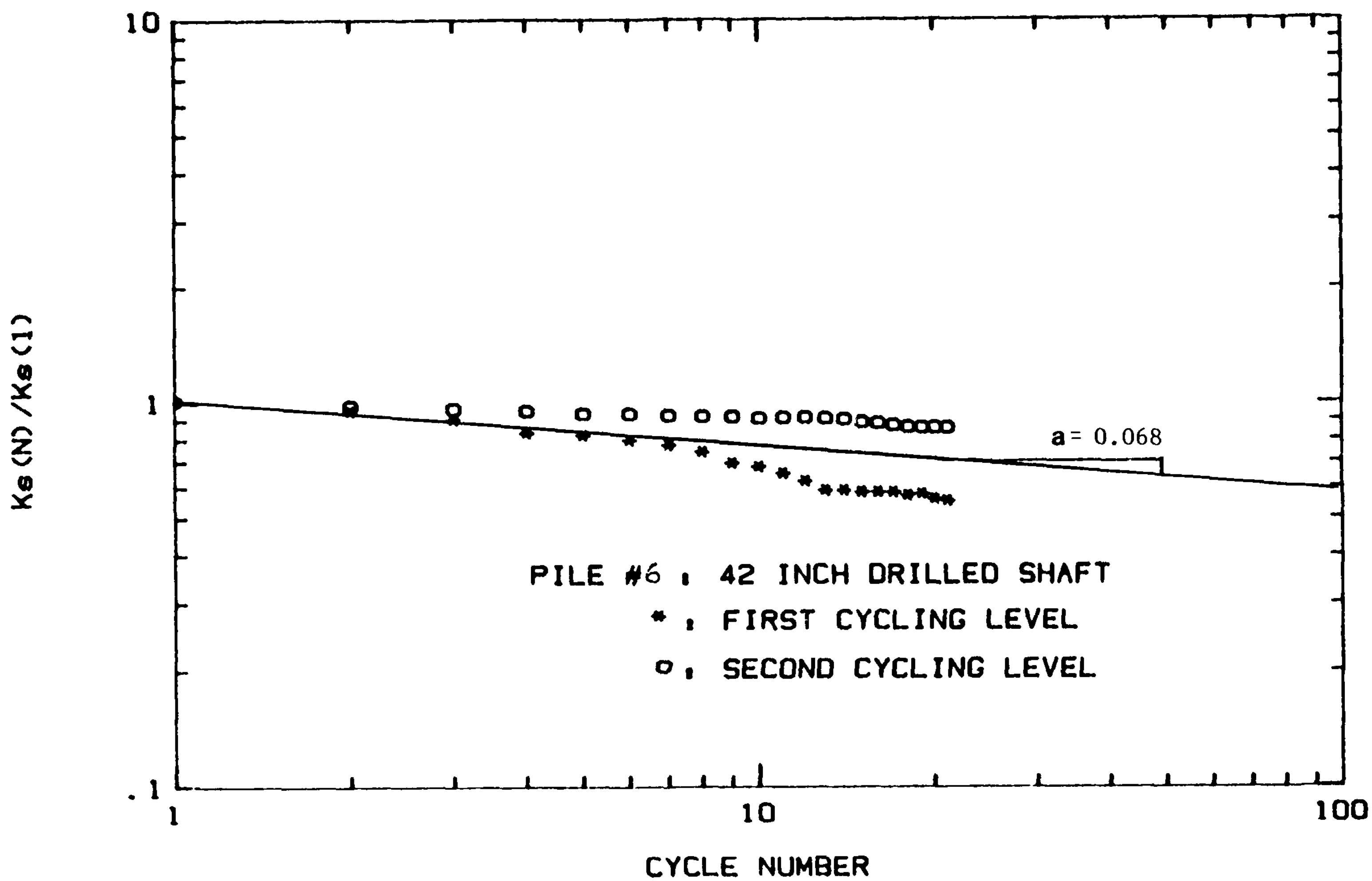



FIGURE 30. Measured Secant Shear Modulus Degradation for Pile No. 6.

When comparing the "a" values, it becomes clear that cycling with total unloading causes greater degradation than cycling with only partial unloading (one-half of the top load). This may be the result of greater inward yielding of the soil as the pile is passed through a greater range of displacements.

Also evident from the "a" values is that the first series of cycles were generally more damaging than the following series. This behavior was true for all except the 20-in square prestressed concrete pile. As discussed earlier, a probable reason for the greater degradation in the first cyclic series of the concrete drilled shafts is the decrease in the piles' flexural stiffness. The prestressing in the square concrete pile postponed the crack propagation until the second series of cycles. However, the steel pipe pile also had less degradation during the second series of cycles with "a" values of 0.065 and 0.059 respectively. Assuming that the flexural stiffness of the steel pipe pile itself suffered little or no degradation, it would appear that the soil stiffness also suffers less degradation at the higher load level. The first series of cycles may have caused a slight densification of the soil in front of the pile.

The cyclic stiffness for the pile $K_{C(N)}$, as defined in Figure 31, showed little or no degradation within each portion of the cyclic loading where the difference between the upper and lower loads was constant (Figures 32 through 37). The cyclic stiffnesses were stiffer for cycling where the magnitude of the difference was one-half of the upper load level. This is to be expected from a non-elastic medium.

#### 4.4.3 Creep response

Taking readings every minute for five minutes after reaching a specified load allowed observation of the creep response of the piles. These responses are presented in

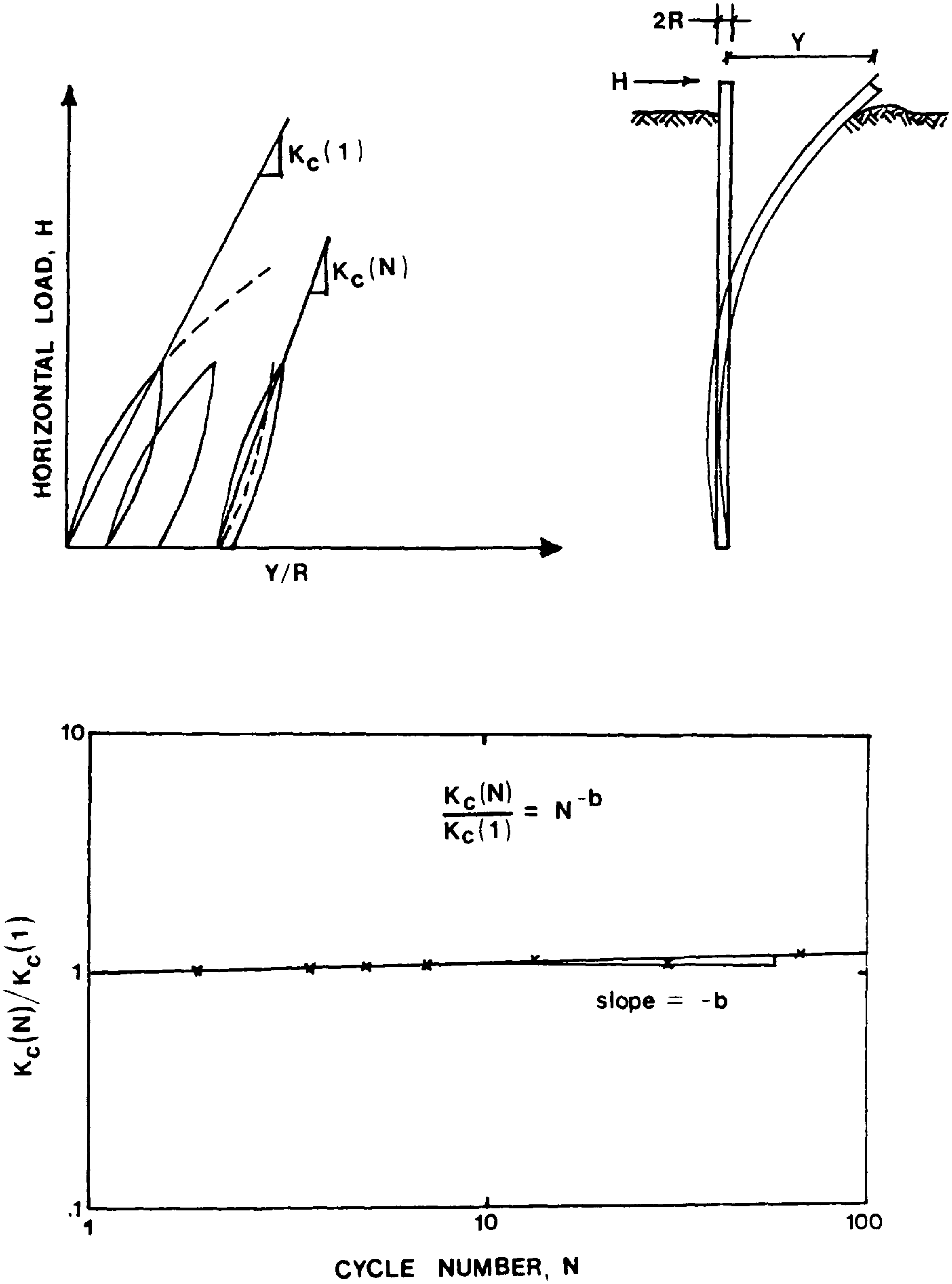



FIGURE 31. Cyclic Shear Modulus Parameters Definition.

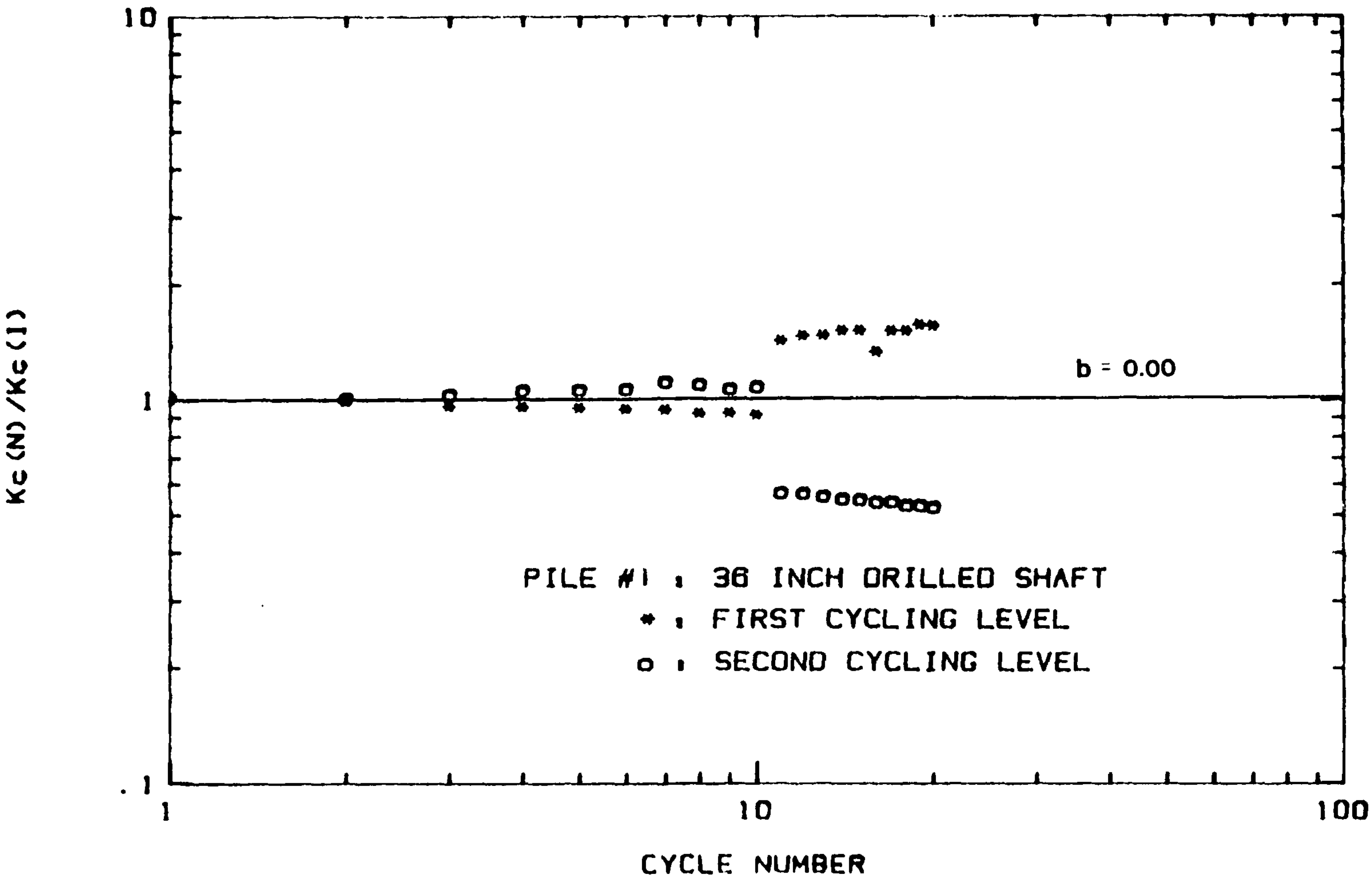



FIGURE 32. Measured Cyclic Shear Modulus Degradation for Pile No. 1.

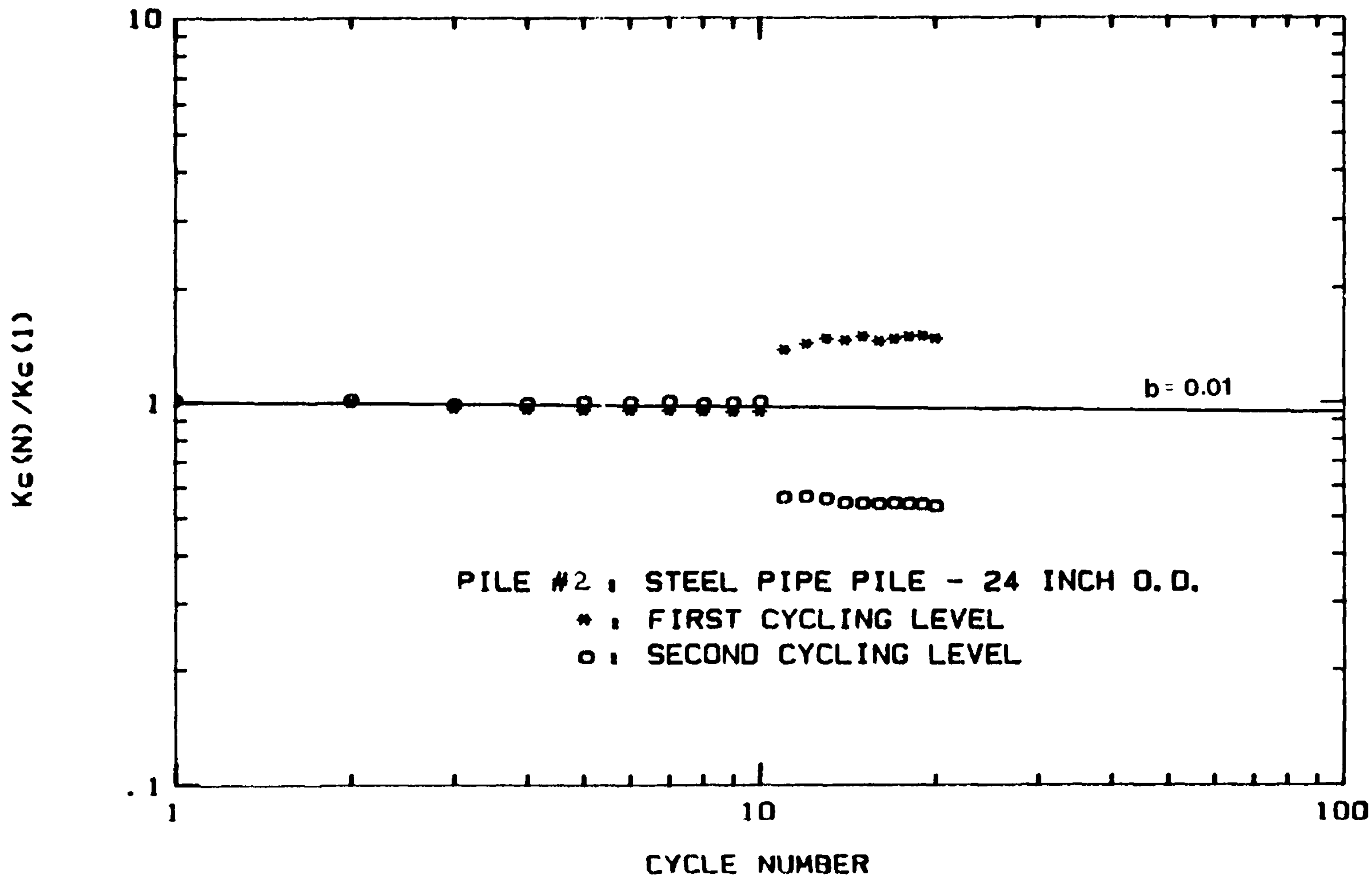



FIGURE 33. Measured Cyclic Shear Modulus Degradation for Pile No. 2.

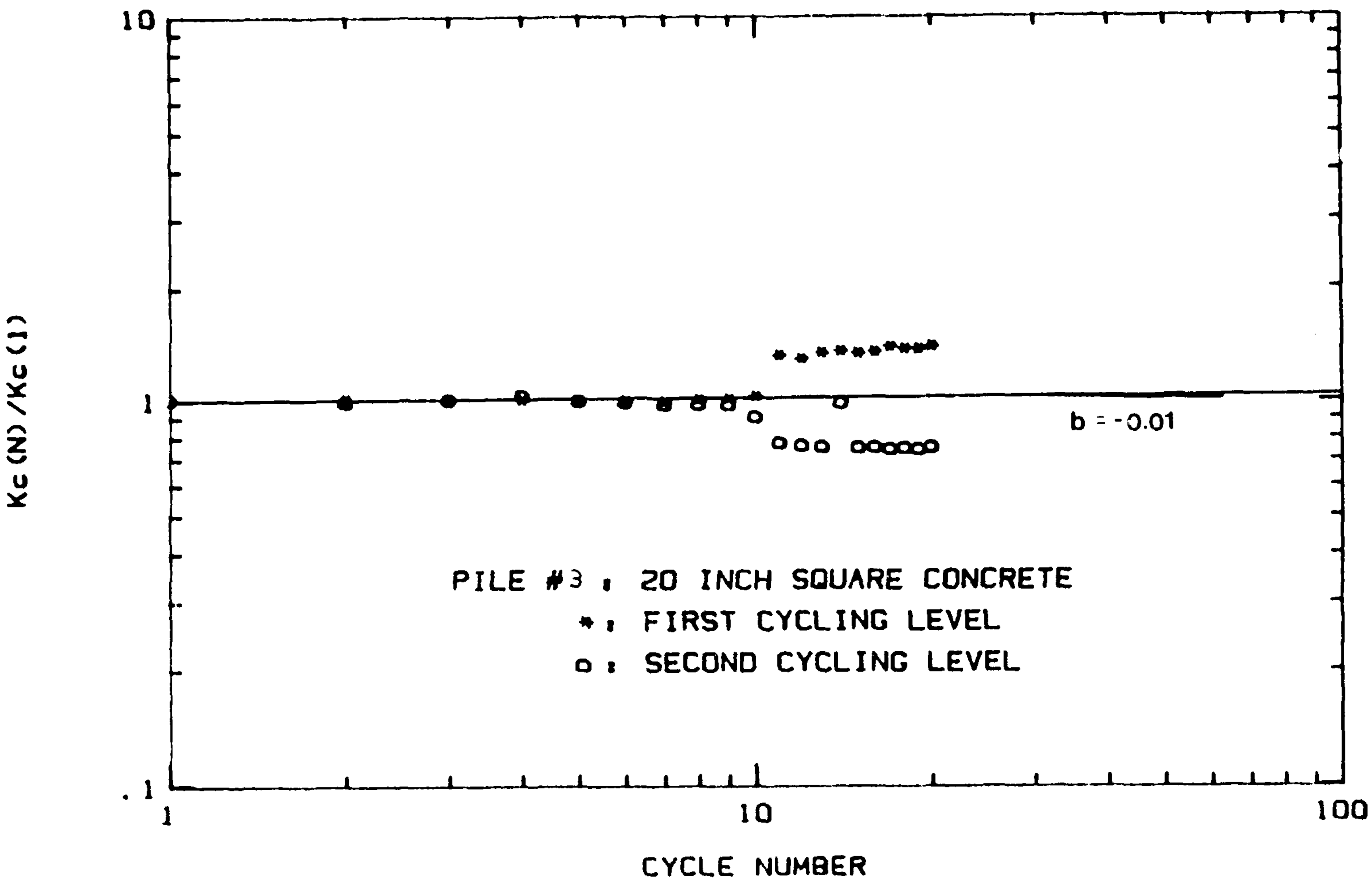



FIGURE 34. Measured Cyclic Shear Modulus Degradation for Pile No. 3.

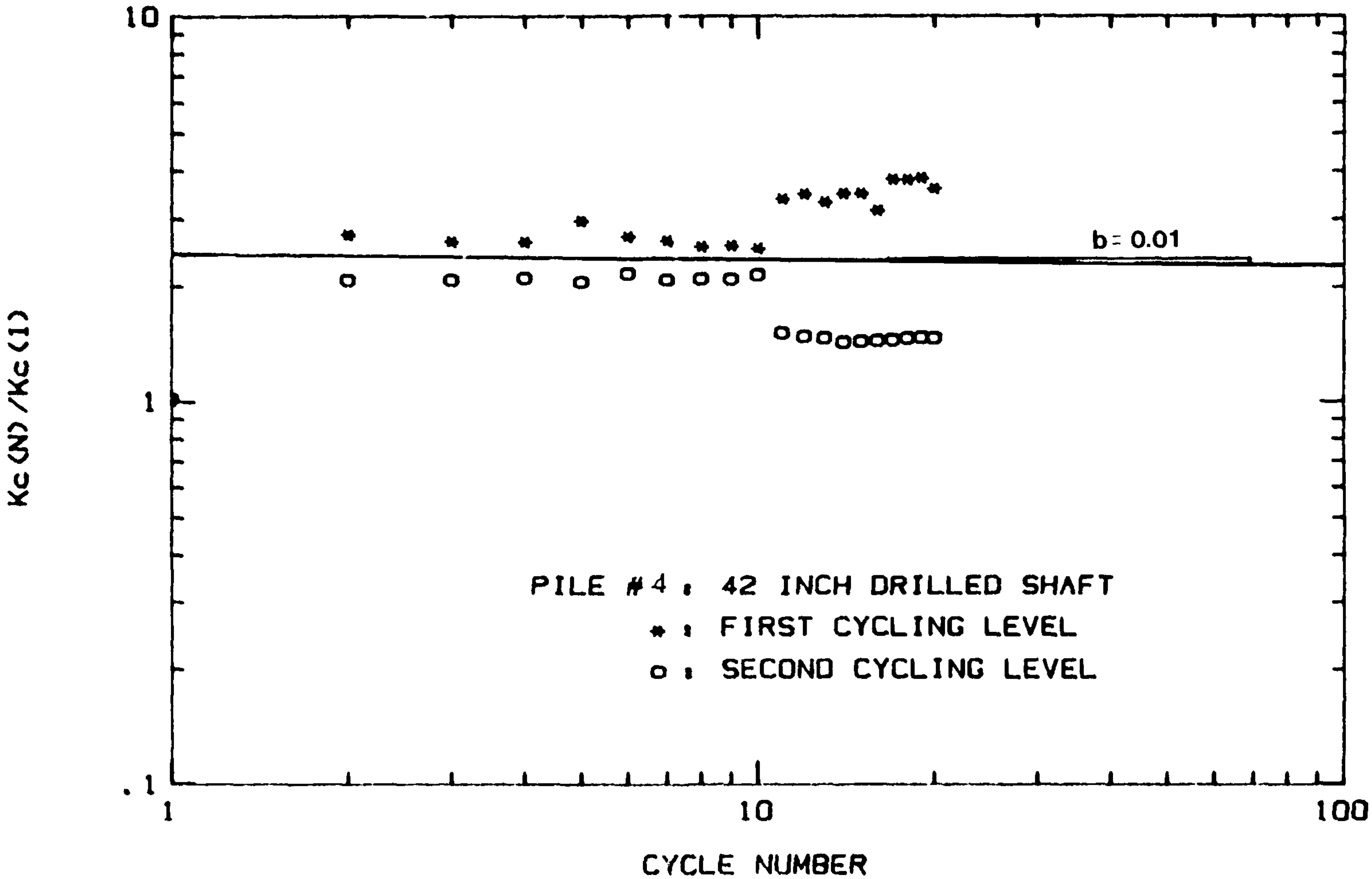



FIGURE 35. Measured Cyclic Shear Modulus Degradation for Pile No. 4.

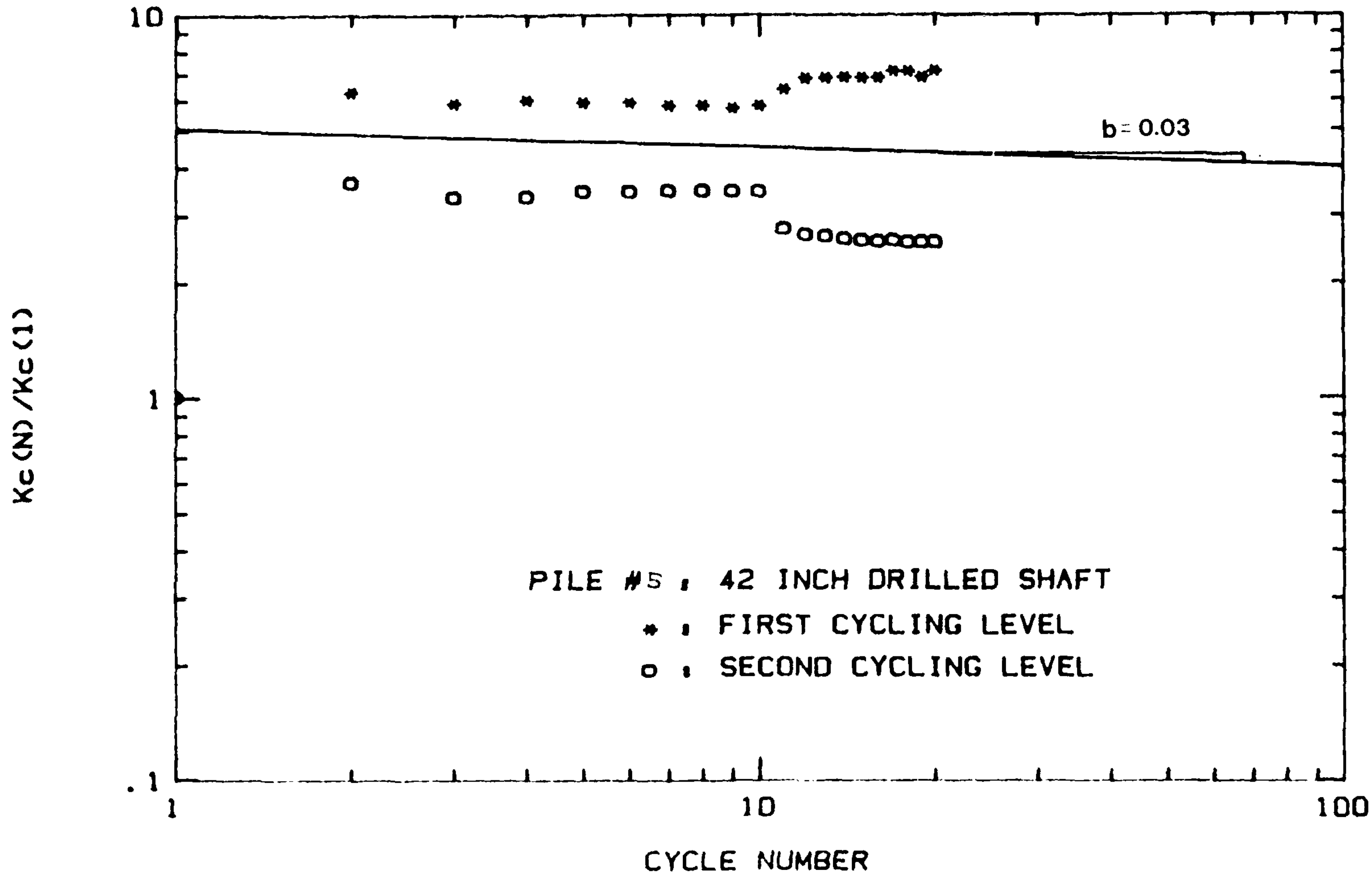



FIGURE 36. Measured Cyclic Shear Modulus Degradation for Pile No. 5.

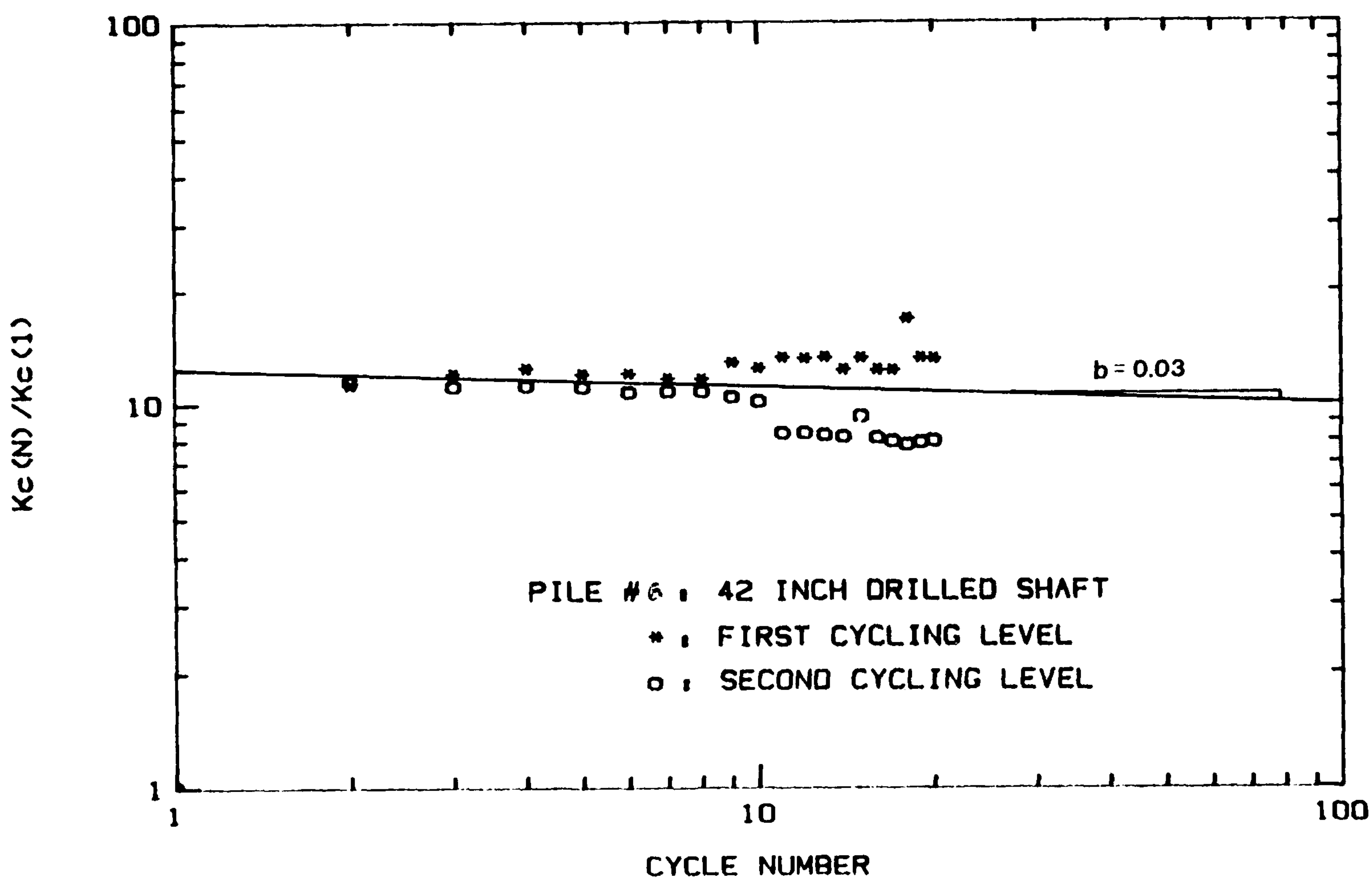



FIGURE 37. Measured Cyclic Shear Modulus Degradation for Pile No. 6.

Figures 38 through 43. These figures show the values $S_n/S_o$, the displacement at time $T_n$ divided by the displacement at time $T_o$ when the load was initially applied, plotted as a function of the values $T_n/T_o$ on a log-log scale. The slope of each line may then be defined as the creep exponent n:

$$\frac{S_n}{S_o} = \left(\frac{T_n}{T_o}\right)^n \tag{1}$$

Values of n are plotted against the lateral load in Figures 44 through 49. From these figures it can be seen that the creep exponent for two of the 42-in diameter drilled shafts (Piles 4 and 5) dropped from an initially high value to a fairly stable value of about 0.02. The creep exponent for the third 42-in diameter drilled shaft (Pile 6) dropped similarly at first down to the 0.02 level, but then began to climb as the test progressed. The initial high creep may not only be a reflection of initial soil creep, but also the creep associated with crack propagation in the concrete piles. The stabilization of the n value aroung 0.02 indicates that the cracking had stabilized. The upward turn in the n values for pile 6 is indicative of the impending pile failure at 90 kips.

The 36-in diameter drilled shaft behaved similarly to the 42-in diameter drilled shafts, with the values of n dropping initially and stabilizing around 0.015. The steel pipe pile and square prestressed concrete pile had much lower initial n values. This is consistent with the theory that the high initial creep for the drilled shafts relects creep associated with crack propagation in the concrete.

The prestressed concrete pile reached a critical creep load at 90 kips. At this sustained load the increase in deflection began to rise rapidly (Figure 46).

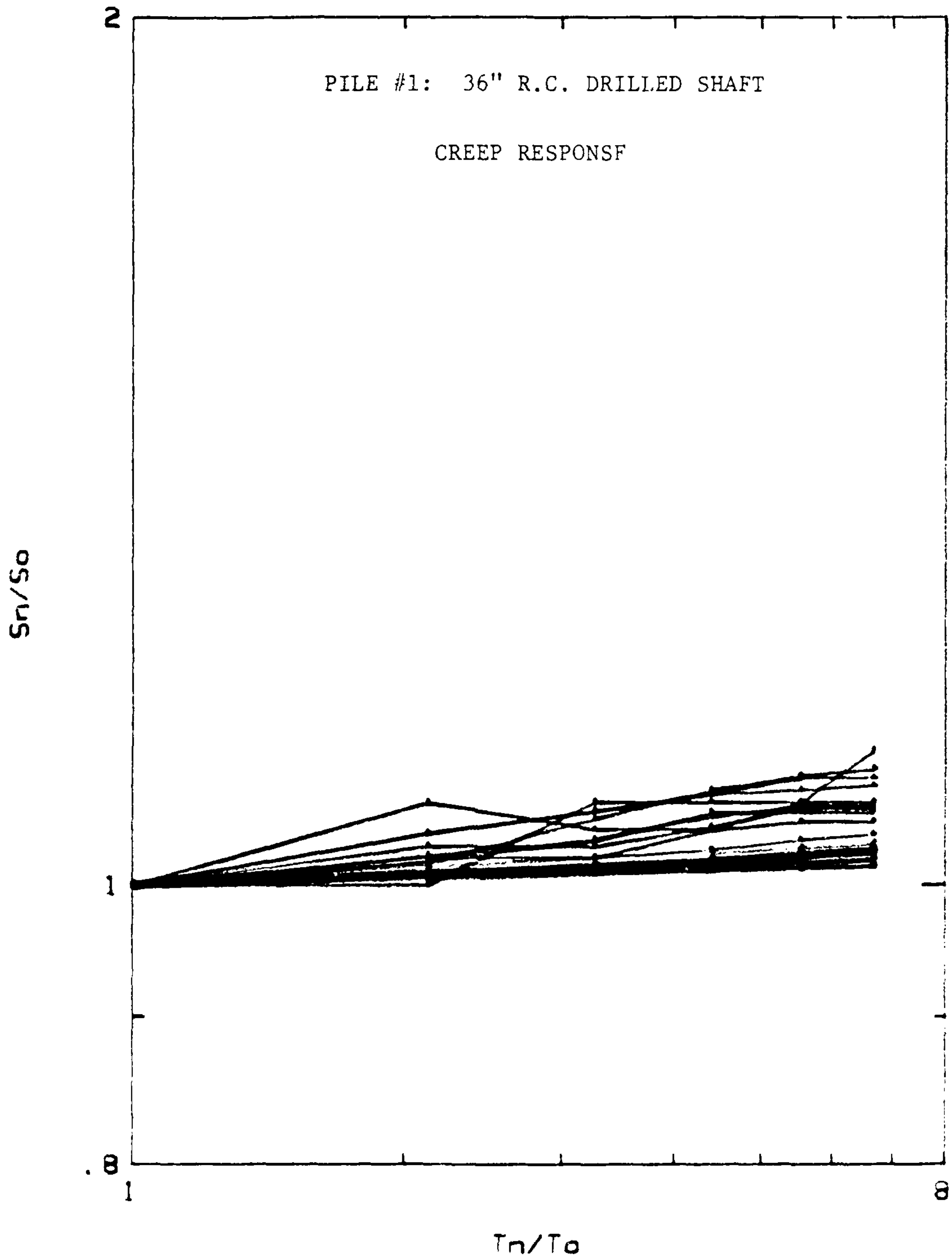



FIGURE 38. Measured Creep Response, Pile No. 1.

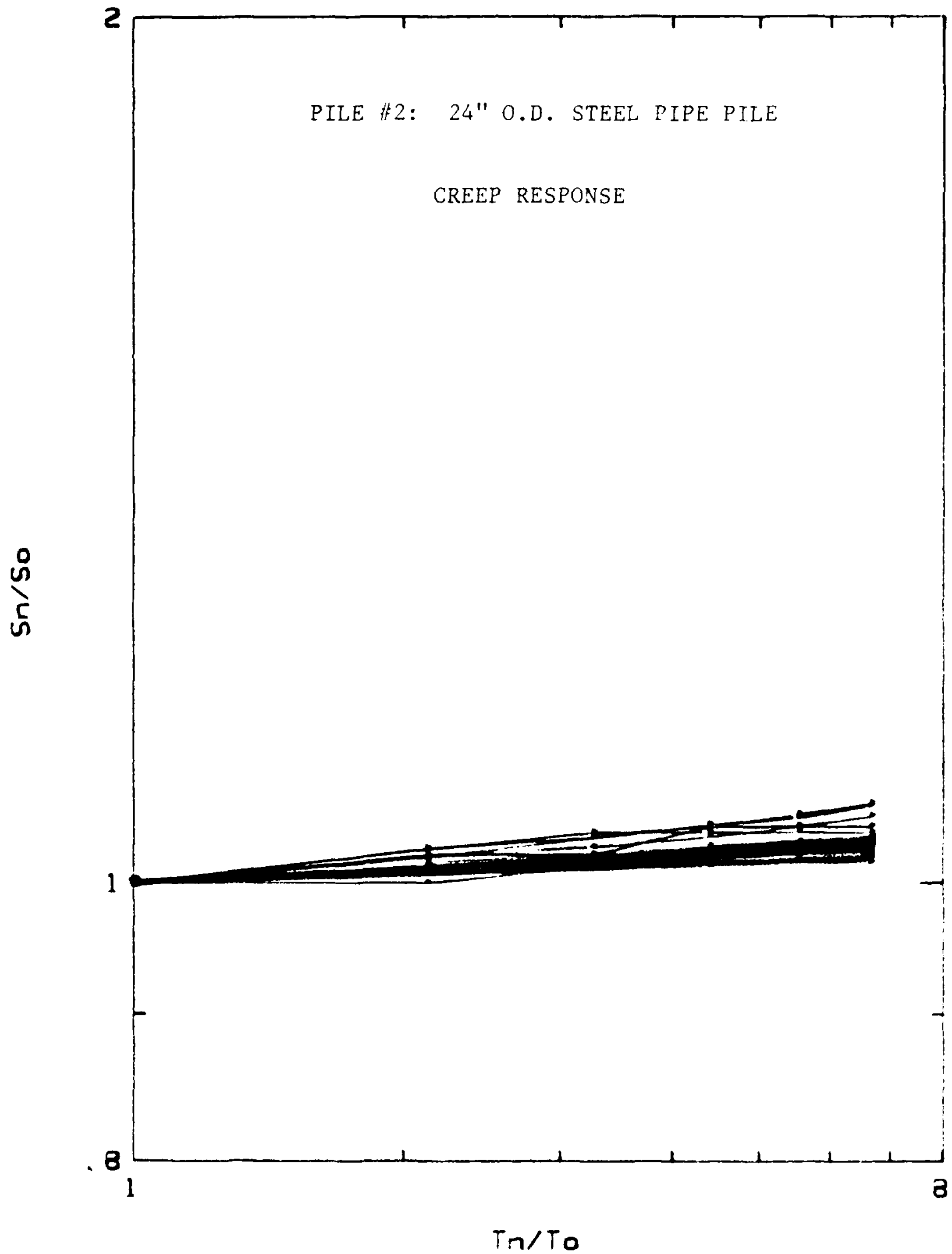



FIGURE 39. Measured Creep Response, Pile No. 2.

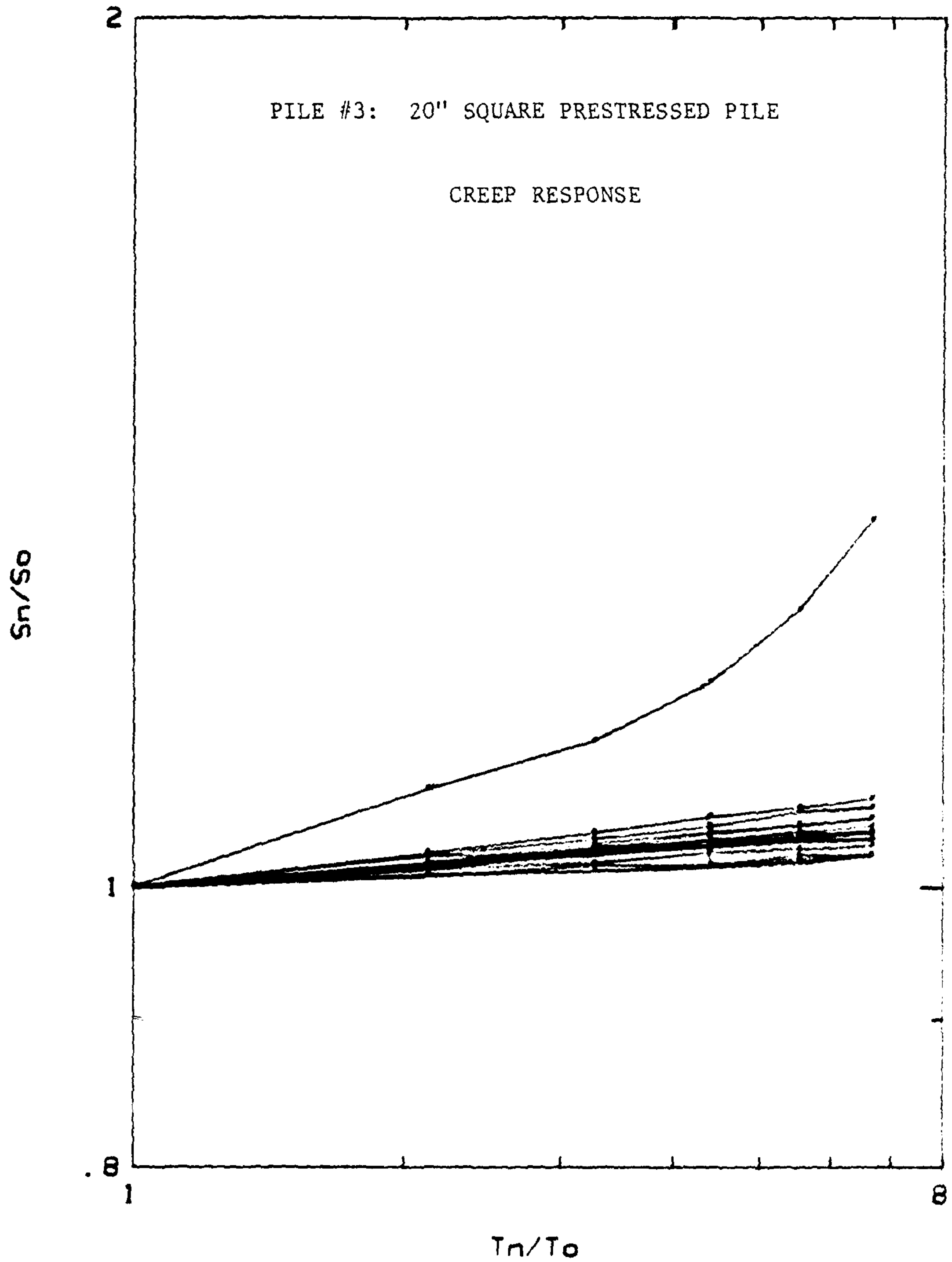



FIGURE 40. Measured Creep Response, Pile No. 3.

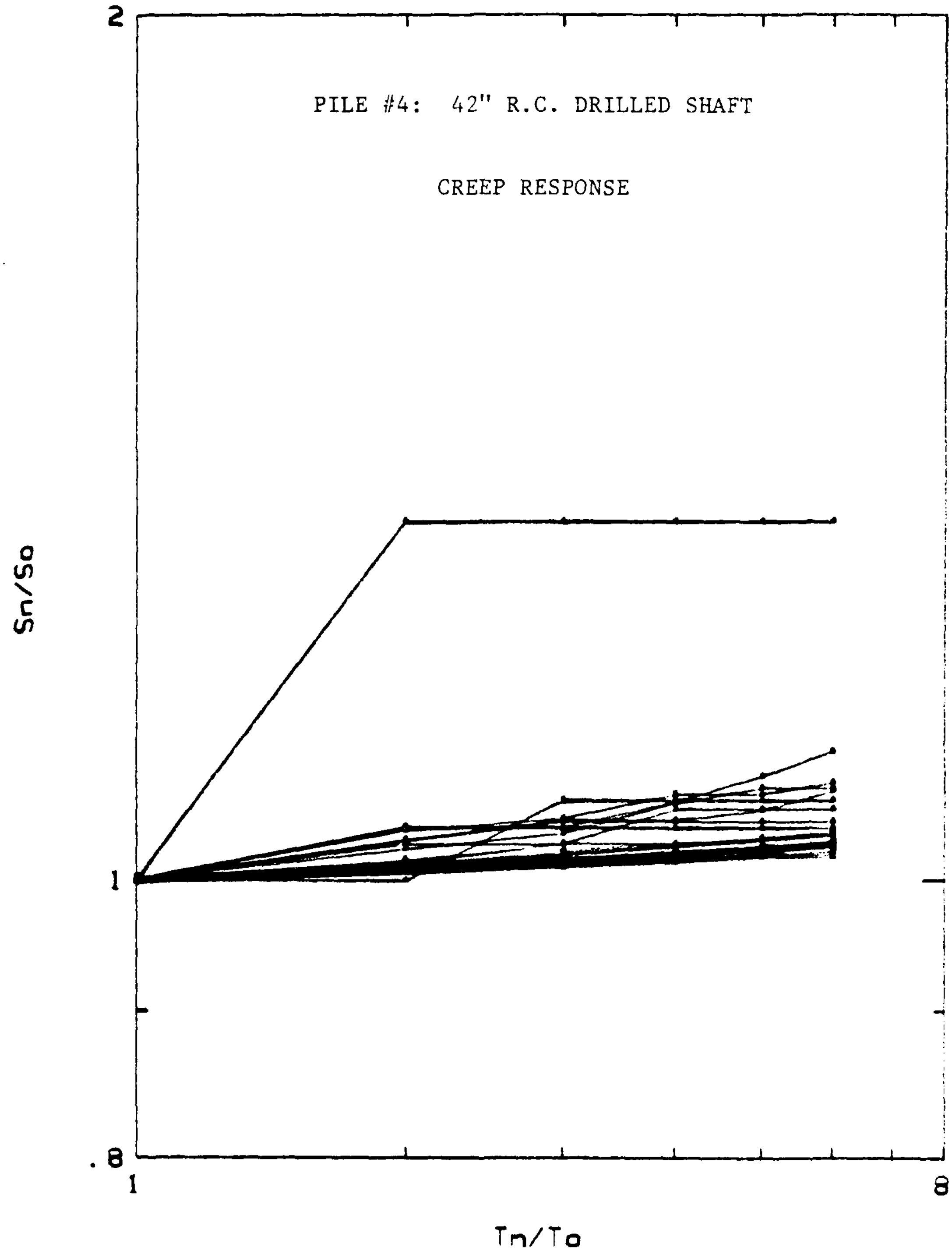



FIGURE 41. Measured Creep Response, Pile No. 4.

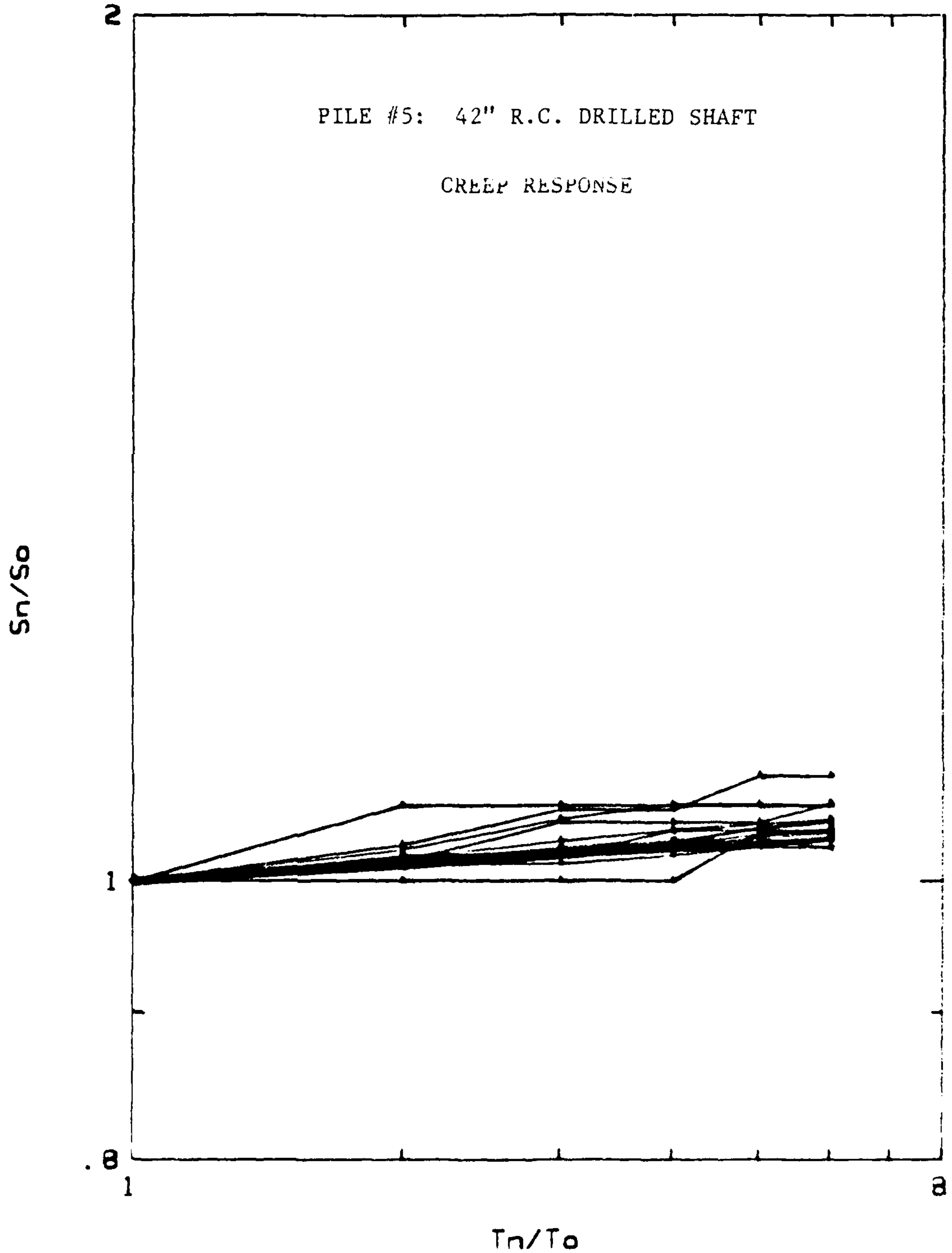



FIGURE 42. Measured Creep Response, Pile No. 5

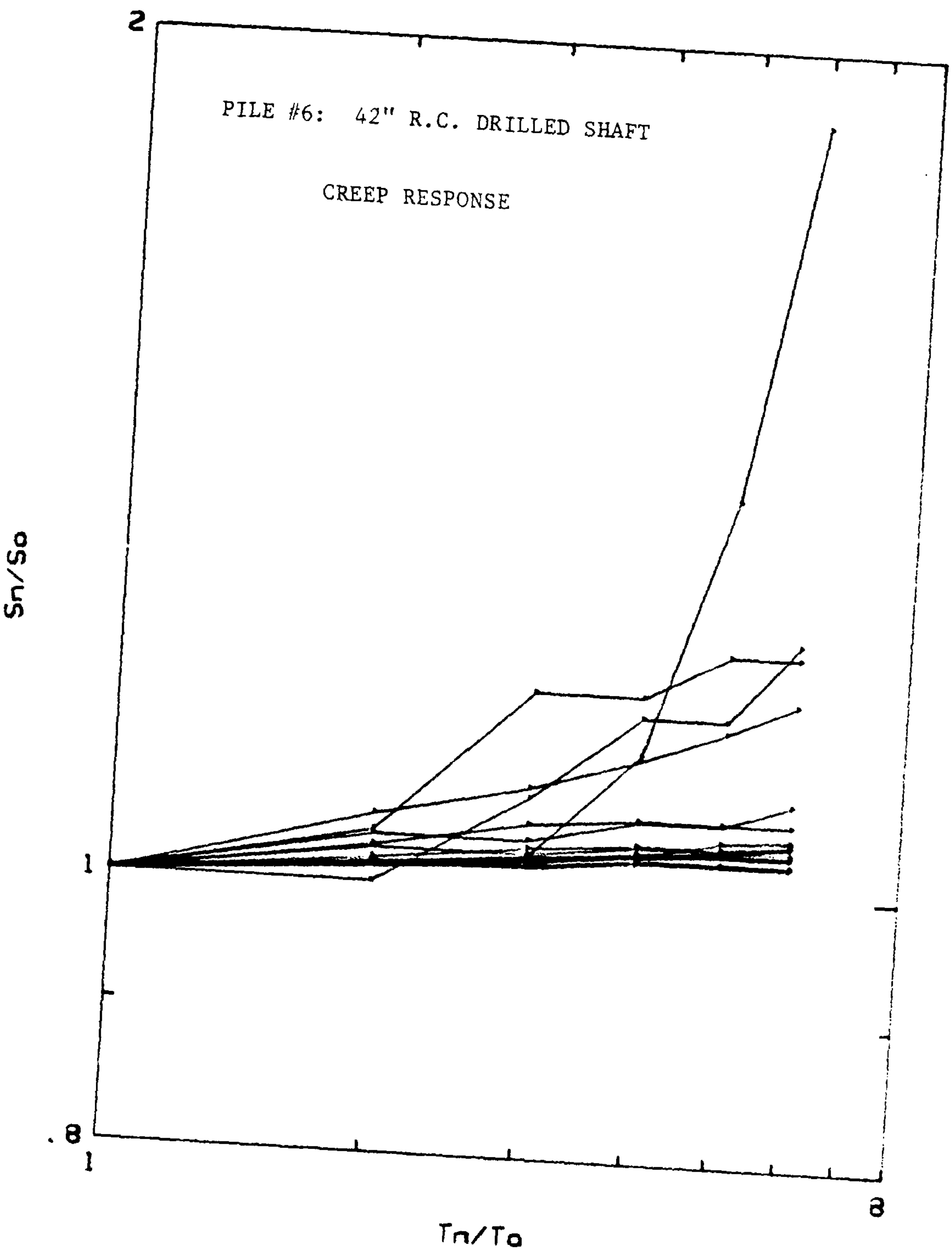



FIGURE 43. Measure Creep Response, Pile No. 6.

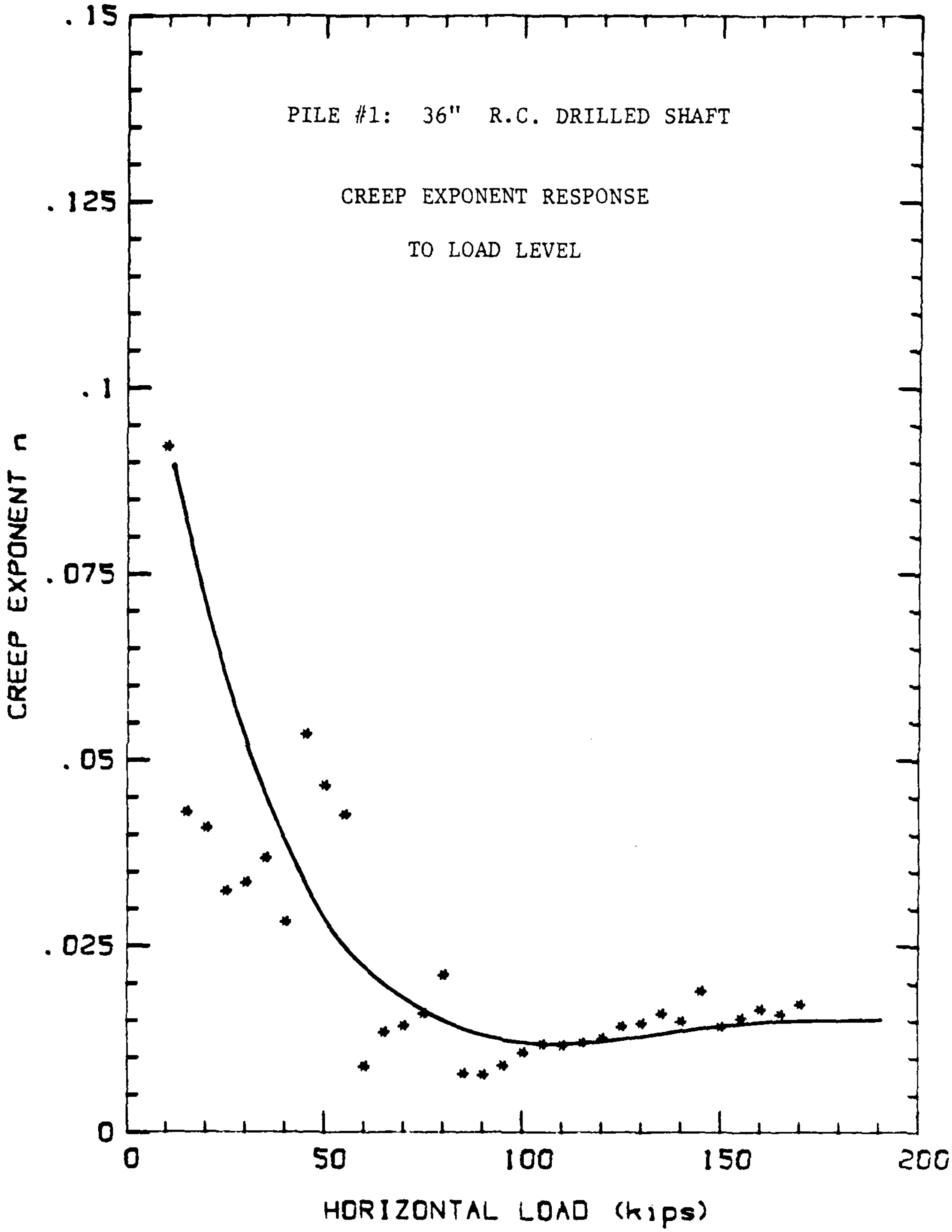



FIGURE 44. Creep Exponent Response to Load Level, Pile No. 1.

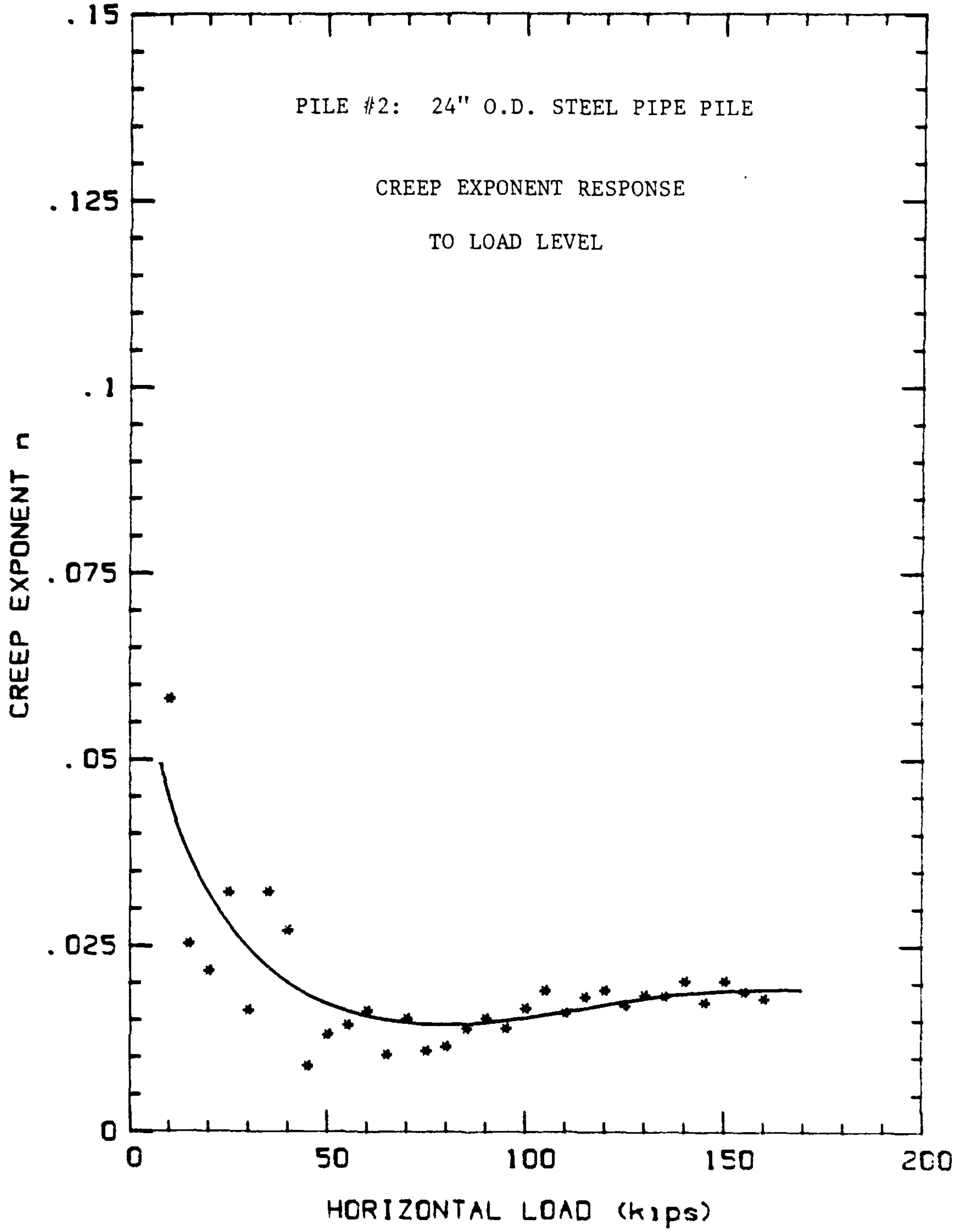



FIGURE 45. Creep Exponent Response to Load Level, Pile No. 2.

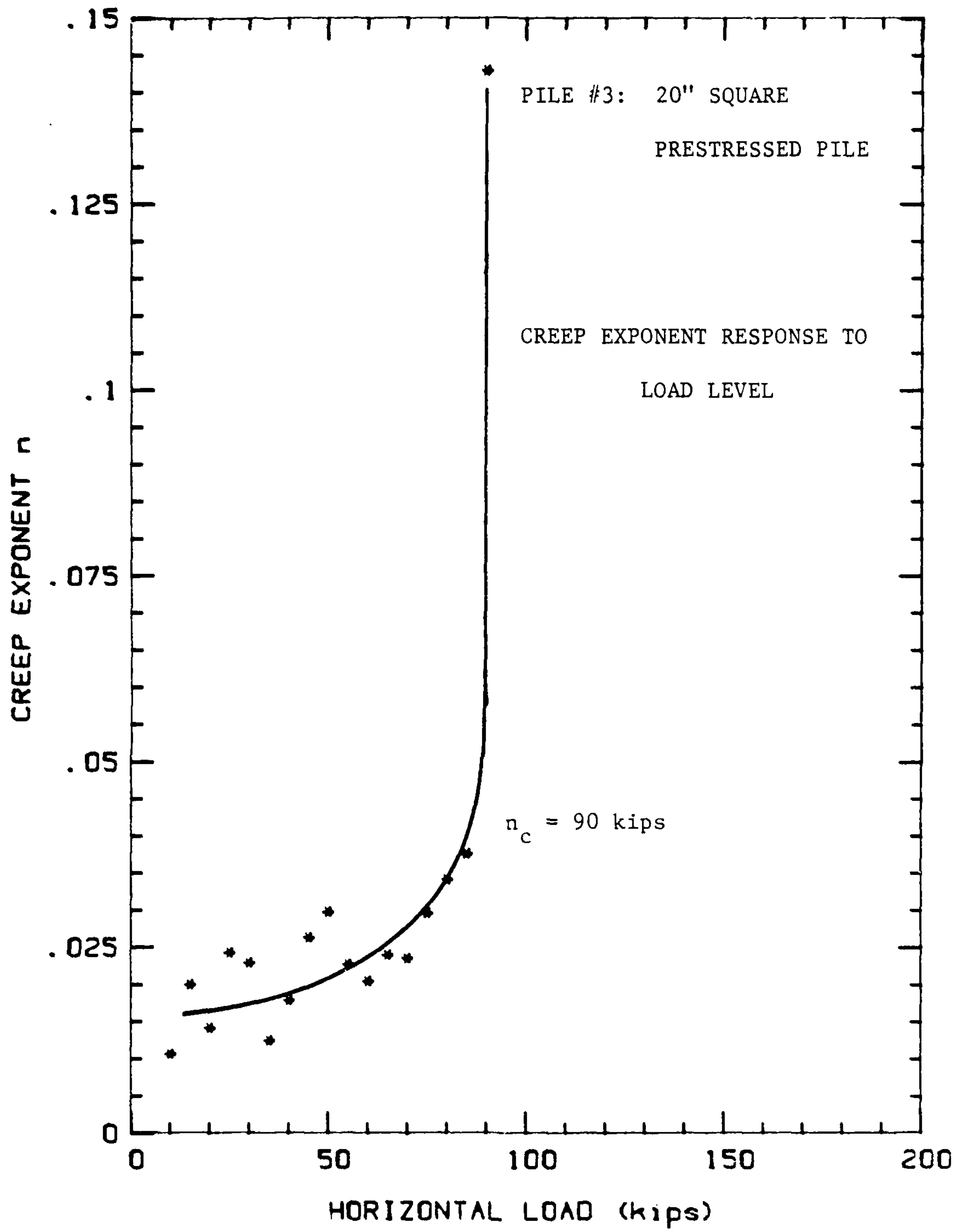



FIGURE 46. Creep Exponent Response to Load Level, Pile No. 3.

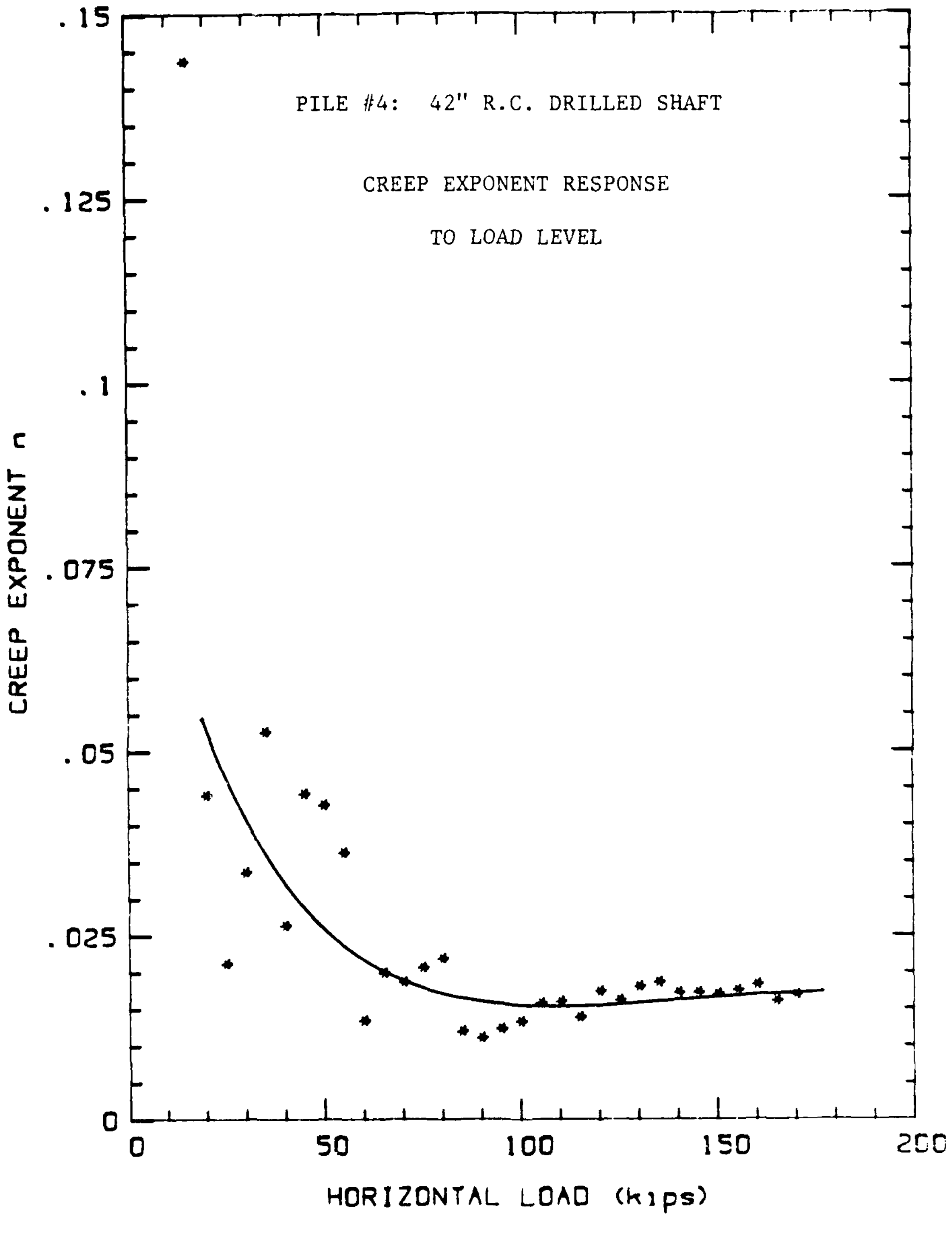



FIGURE 47. Creep Exponent Response to Load Level, Pile No. 4.

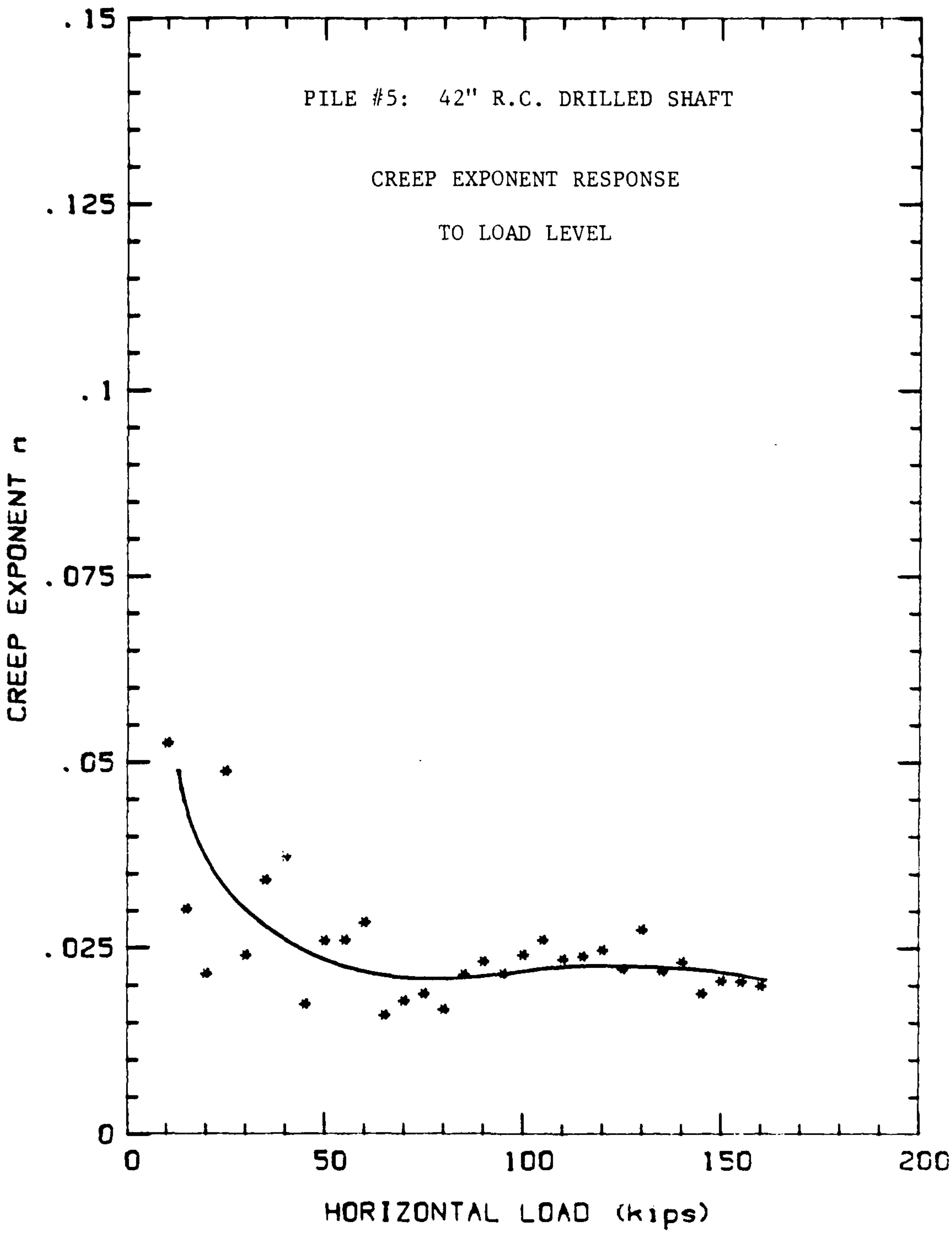



FIGURE 48. Creep Exponent Response to Load Level, Pile No. 5.

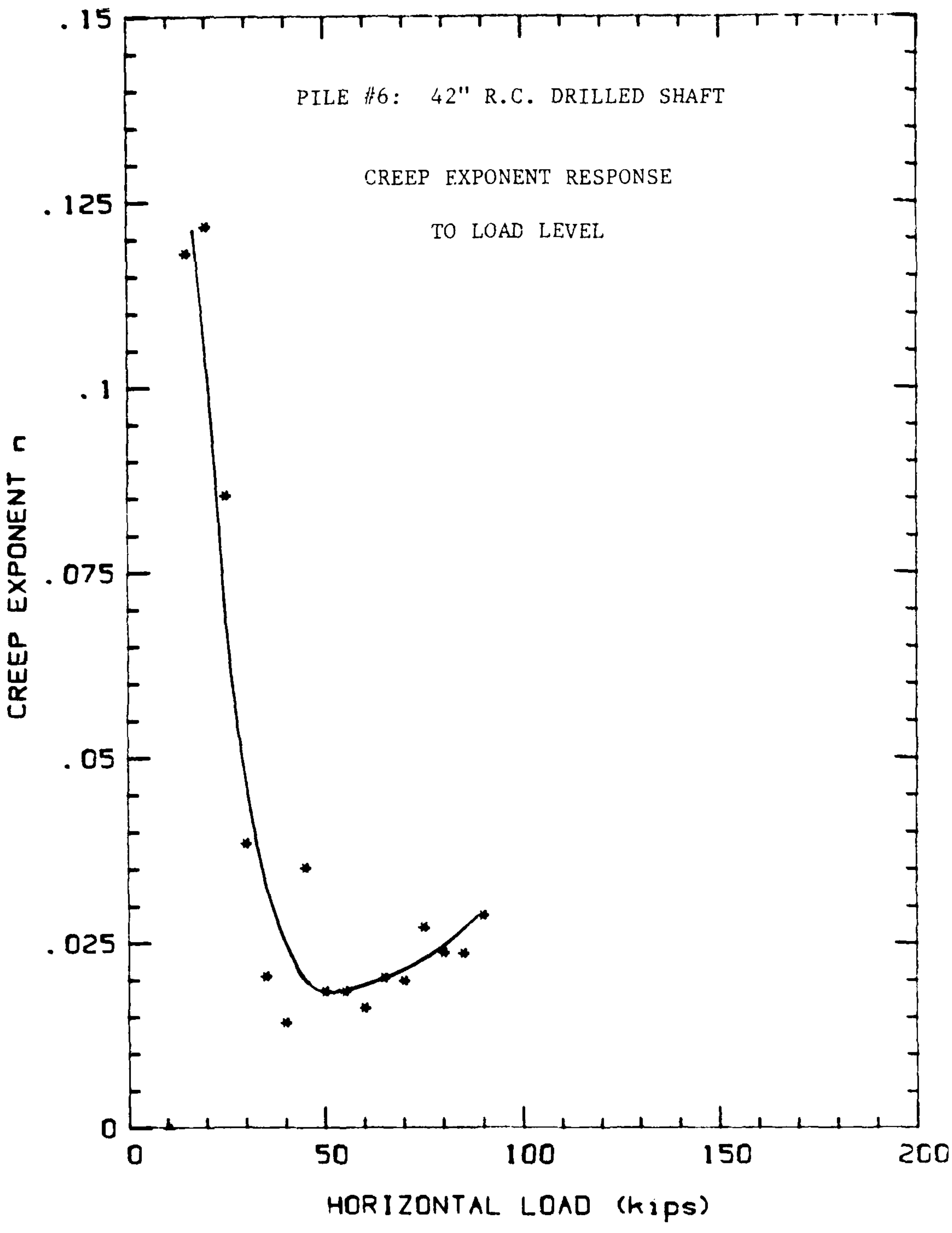



FIGURE 49. Creep Exponent Response to Load Level, Pile No. 6.

## 5. THE PRESSUREMETER TESTS

### 5.1 PMT Tests at the Site

Two series of pressuremeter tests were conducted prior to the lateral pile load tests and one series of tests afterwards. The first series was conducted in conjunction with the vertical pile load tests and consisted of prebored pressuremeter tests using the TEXAM PMT system (Briaud Engineers, 1986). This test series was performed in June 1986 and included two cone penetrometer test (CPT) soundings, but did not include any cyclic or creep tests. The second series, performed in December 1986, included both prebored TEXAM PMT and driven cone-pressuremeter (CPMT) tests with cyclic and creep tests under pressure-controlled conditions. These tests were concentrated within the upper layers of the soil which have the greatest impact on the response of laterally loaded piles. The third series, performed in January 1987, was also composed of both prebored TEXAM PMT and driven CPMT tests. The tests were conducted after the lateral load testing of the piles to investigate the changes in the soil response following the pile load tests.

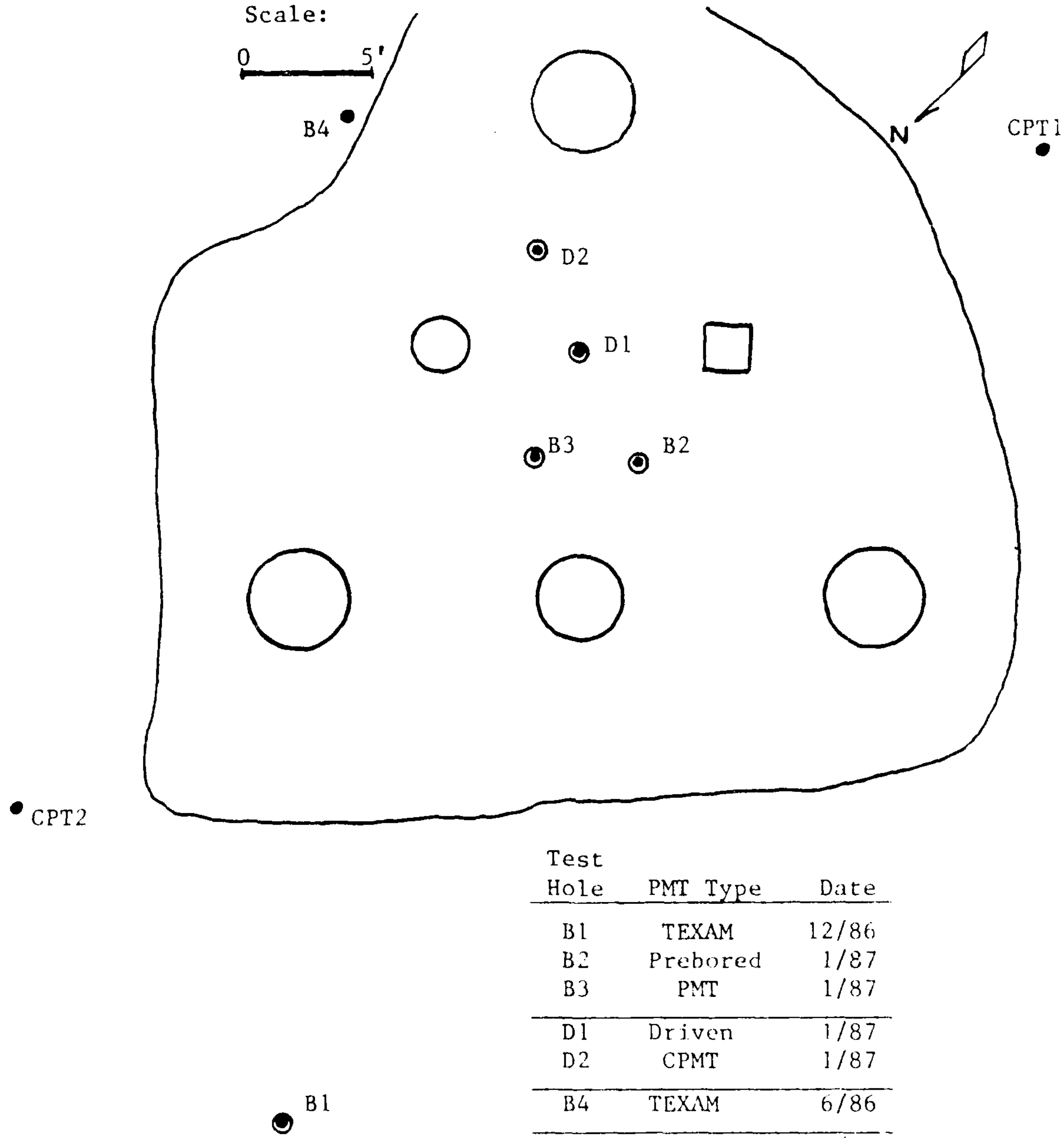
The locations of the tests are indicated on the summary of in-situ tests shown in Figure 50. Corrected pressuremeter curves for the cyclic PMT tests used in this report are included in Appendix B.

### 5.2 PMT Moduli and Net Limit Pressure

The pressuremeter first load moduli, reload moduli and net limit pressure profiles for the site are presented in Figure 51. When compared to the data from the other geotechnical investigators (presented in Section 2) it can be seen that the PMT data confirms the general stratigraphy shown in Figure 3.

### 5.3 Prebored TEXAM PMT and Driven CPMT Test Results

The PMT tests performed prior to the lateral pile load tests were used to generate the monotonic P-y curves for




| Test Hole | PMT Type | Date |
|---|---|---|
| B1 | TEXAM | 12/86 |
| B2 | Prebored | 1/87 |
| B3 | PMT | 1/87 |
| D1 | Driven | 1/87 |
| D2 | CPMT | 1/87 |
| B4 | TEXAM | 6/86 |
| CPT1 | -- | 6/86 |
| CPT2 | | 6/86 |

FIGURE 50. Location of In-Situ Tests at Load Test Site

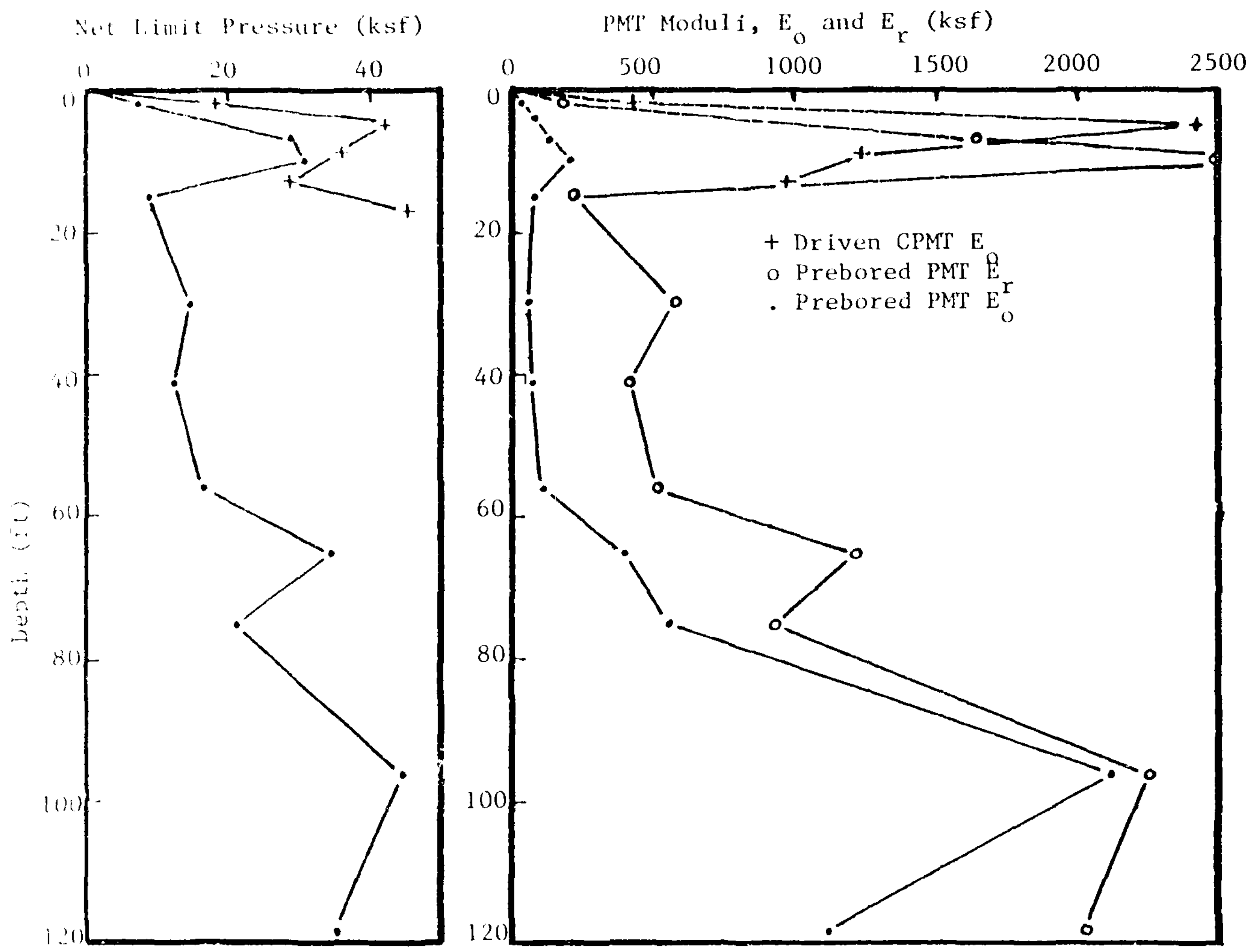



FIGURE 51. Net Limit Pressure, Initial Modulus and Reload Modulus Profiles

each of the pile types and the cyclic degradation and creep response exponents.

### 5.3.1 PMT generated P-y curves

The procedure for generating P-y curves from pressuremeter data is described in detail by Little and Briaud (1987). Generally, the process uses the analogy between the pressuremeter probe's expansion into the in-situ soil and the horizontal displacement of a laterally loaded pile. It provides a series of curves defining the total resistance to lateral displacement that may be expected during lateral loading of a pile within each layer of the soil stratigraphy. These curves are plots of the total soil resistance per unit length of pile, P, against the lateral pile displacement within each stratum, y.

The P-y curves generated from the pressuremeter tests at the load test site are presented in Figures 52 through 56. The first family of curves (Figure 52) were generated for the three 42-in diameter drilled shafts from the prebored TEXAM PMT test results. The P-y curves correspond relatively well to the site stratigraphy as shown in Figure 3. Recalling that the site had been excavated three ft before performance of the lateral load tests, the P-y curves increase in stiffness until a depth of 15 ft. This depth coincides with the first layer of firm clay. The P-y curves in the fine sand layers from 18 to 58 ft are clustered together. The soil resistance shows a marked increase in the dense sand layer 65 ft below the surface, and drops off in the clay layer below 75 ft.

Two different families of P-y curves were produced for the square prestressed concrete pile (Pile 3). Both sets assumed that the pile was a full displacement driven pile. The first set (Figure 53) was generated by using the driven CPMT test results down to 17 ft and using the prebored TEXAM PMT reload curves below 17 ft (Little and Briaud, 1987).

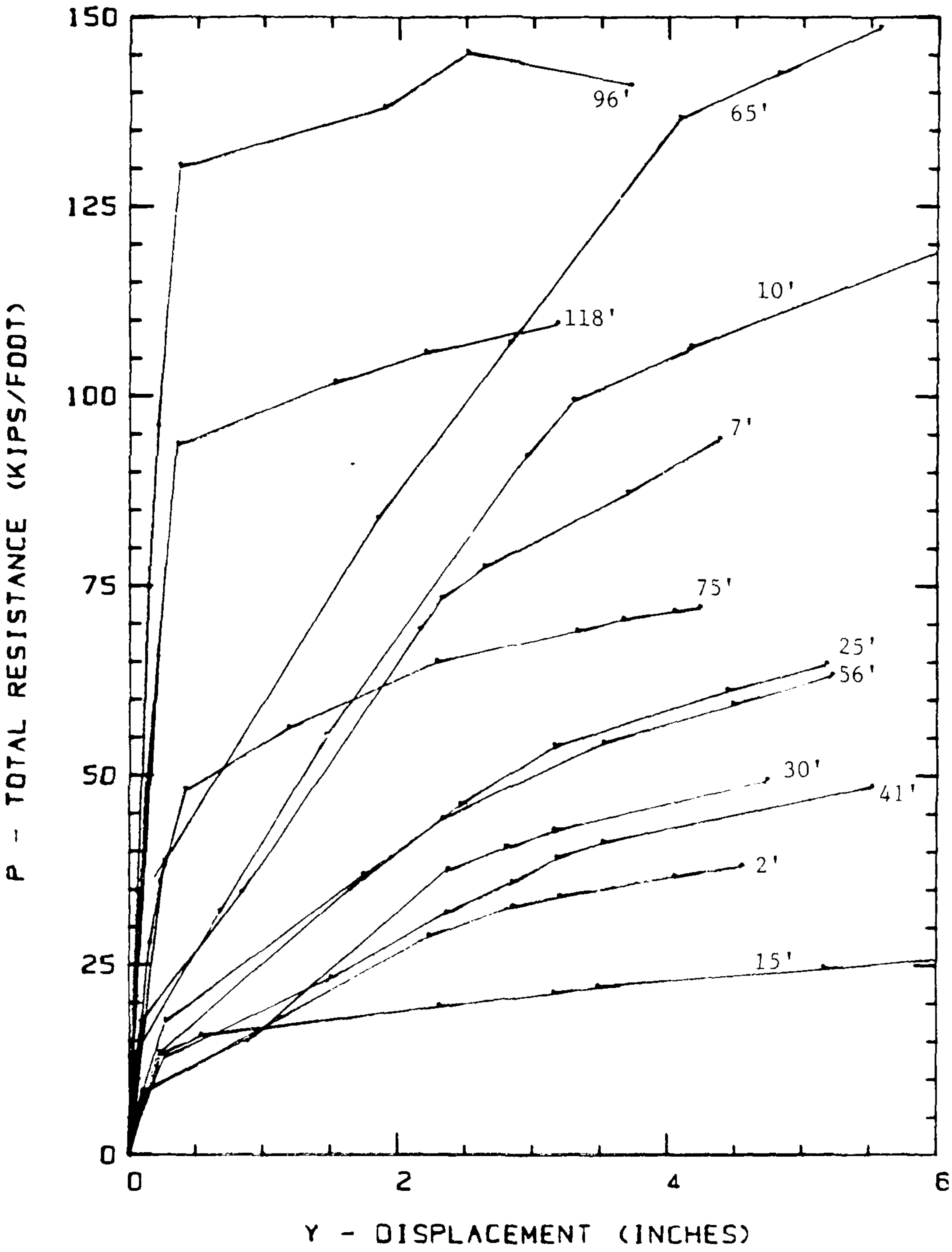



FIGURE 52. Prebored TEXAM PMT Generated P-y Curves for 42" R.C. Drilled Shafts, Pile Nos. 4, 5, and 6.

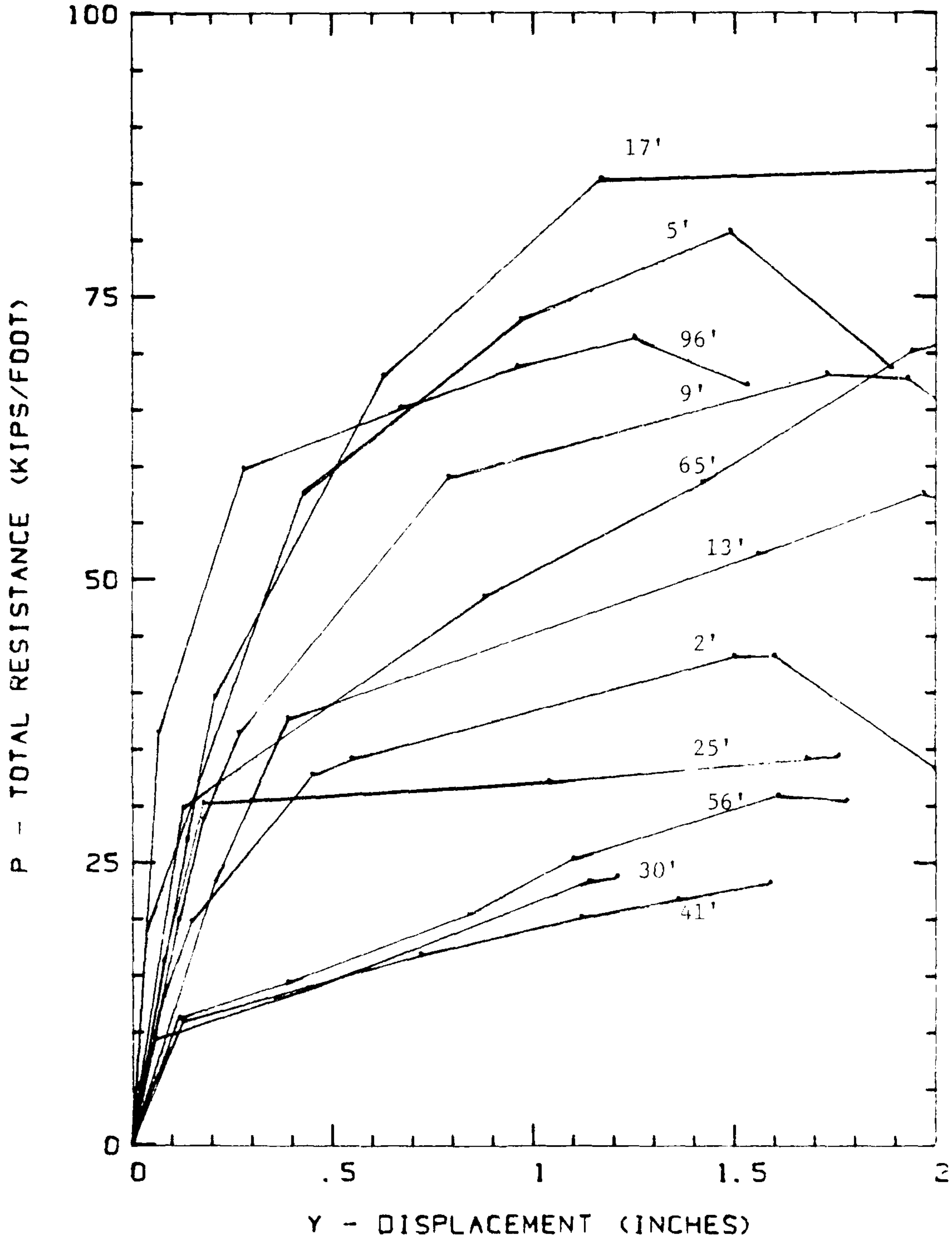



FIGURE 53. Driven CPMT Generated P-y for 20" Square Concrete, Pile No. 3.

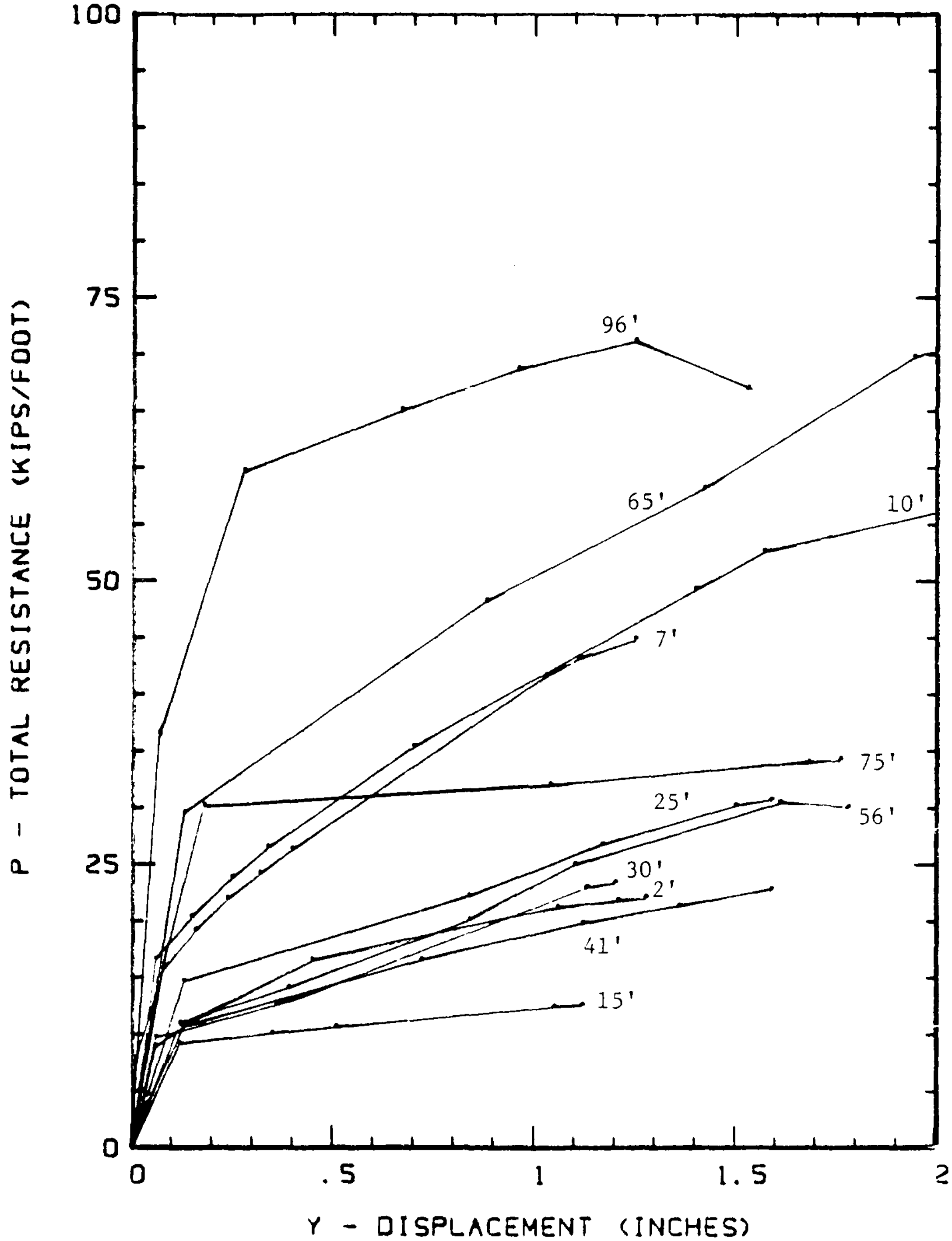



FIGURE 54. Prebored TEXAM PMT Generated P-y Curves for 20" Square Concrete, Pile No. 3.

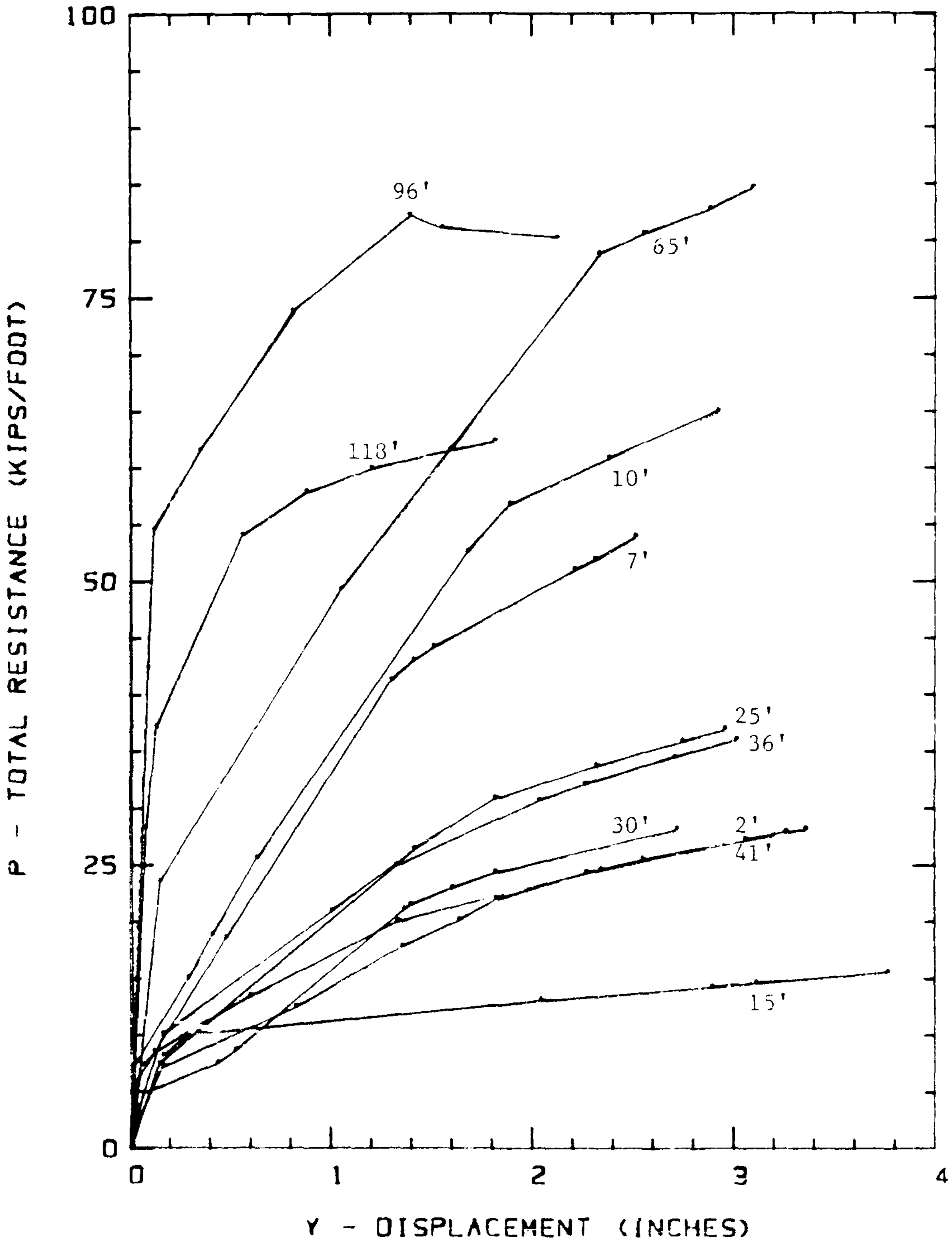



FIGURE 55. Prebored TEXAM PMT Generated P-y Curves for 24" Non-displacement Steel Pipe Pile, Pile No. 2.

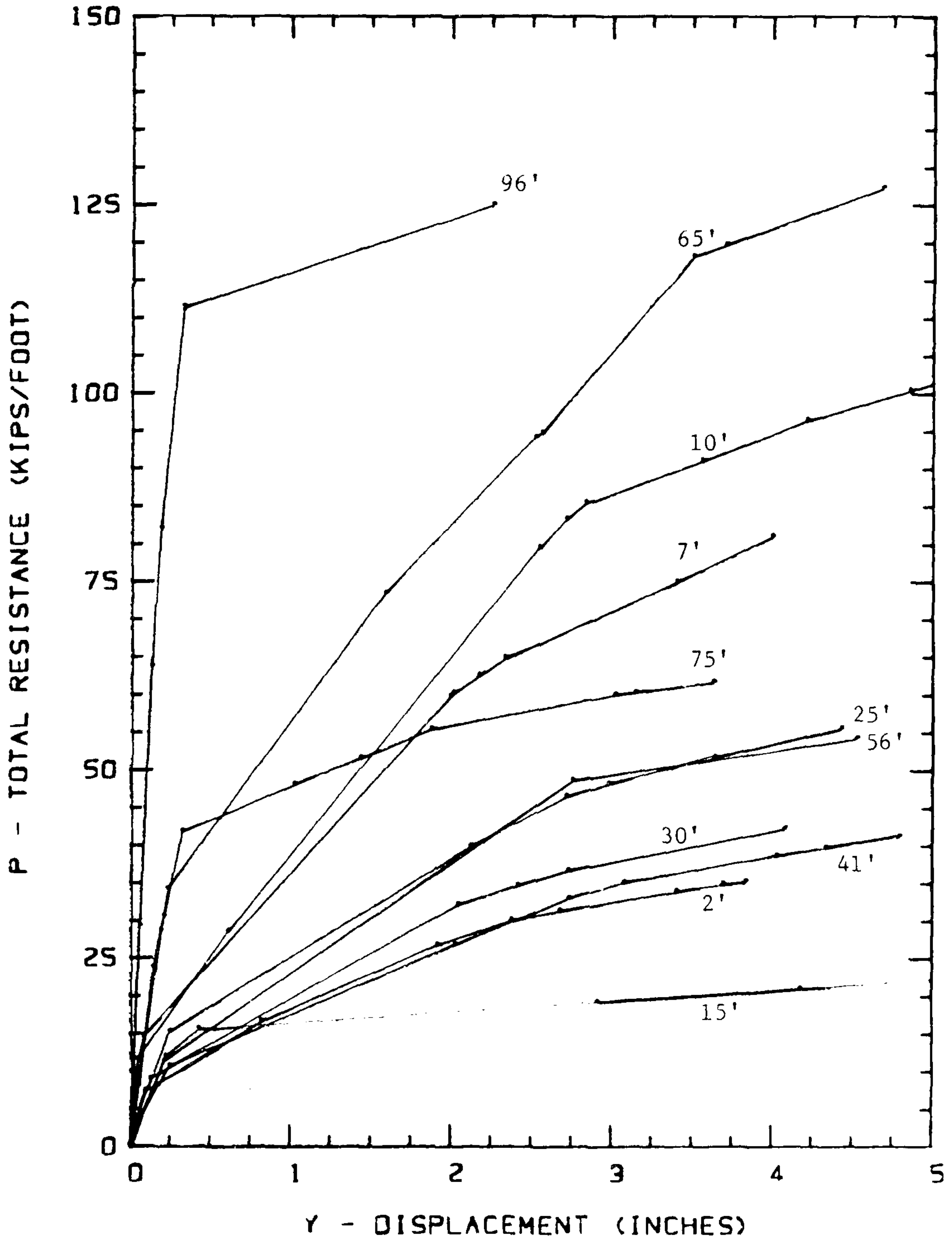



FIGURE 56. Prebored TEXAM PMT Generated P-y Curves for 36" R.C. Drilled Shaft, Pile No. 1.

The second set (Figure 54) was generated using only the prebored TEXAM PMT reload curves. As can be seen in Figures 53 and 54 the driven CPMT tests generally lead to stiffer P-y curves.

The P-y curves for the pipe pile (Figure 55) were generated using the prebored TEXAM PMT test results and assuming that the pile was a non-displacement pile. This assumption is consistent with the fact that the pile did not plug until a significant depth. Therefore, at least in the more important shallow depth region, the pile acted as a non-displacement pile.

The P-y curves for the 36-in diameter drilled shaft (Figure 56) were also generated from the prebored TEXAM PMT test results.

The P-y curves for the 24-in diameter pipe pile and the 36-in diameter drilled shaft prepared using the conventional method (Reese et al., 1974) are shown in Figures 57 and 58. These curves were prepared by McClelland Engineers (1986). Compared to the PMT P-y curves, the conventional P-y curves show a much softer initial response and a lower ultimate soil resistance within the critical upper layers of the soil.

### 5.3.2 Cyclic degradation parameters

The cyclic degradation parameter, a, for the pressuremeter tests represents the degradation of the secant PMT shear modulus with increasing cycles as defined in Figure 59. The $G_{S(N)}/G_{S(1)}$ versus N curves for each test are presented in Appendix C. A summary of the resulting a values for the secant shear modulus degradation is presented in Table 4.

The cyclic degradation parameters for the driven CPMT and the prebored PMT tests at 2 ft depth are less than the a values of larger depths. A possible explanation for the

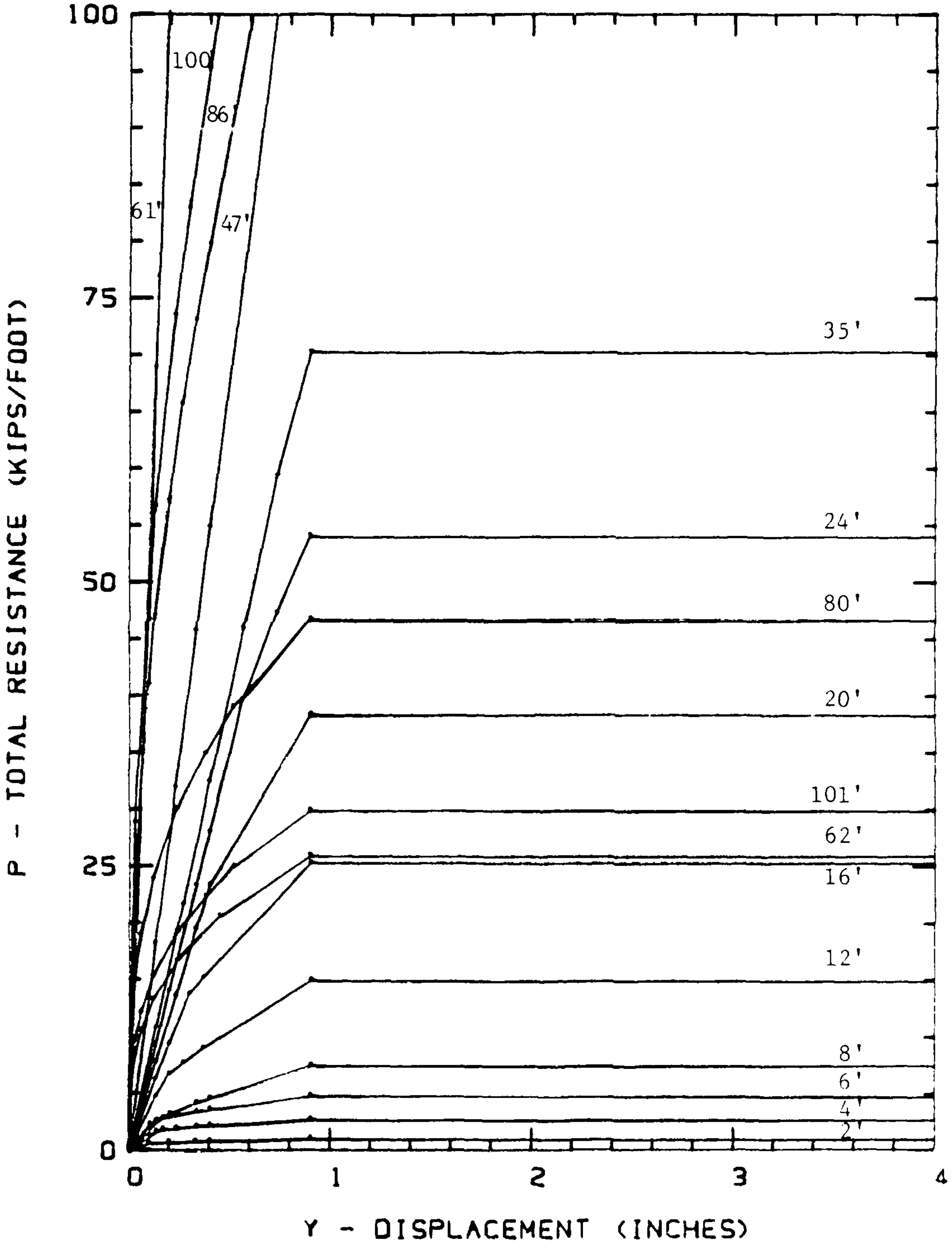



FIGURE 57. Conventionally Prepared P-y Curves for 24" Non-displacement Pipe Pile (McClelland Engineers, 1986).

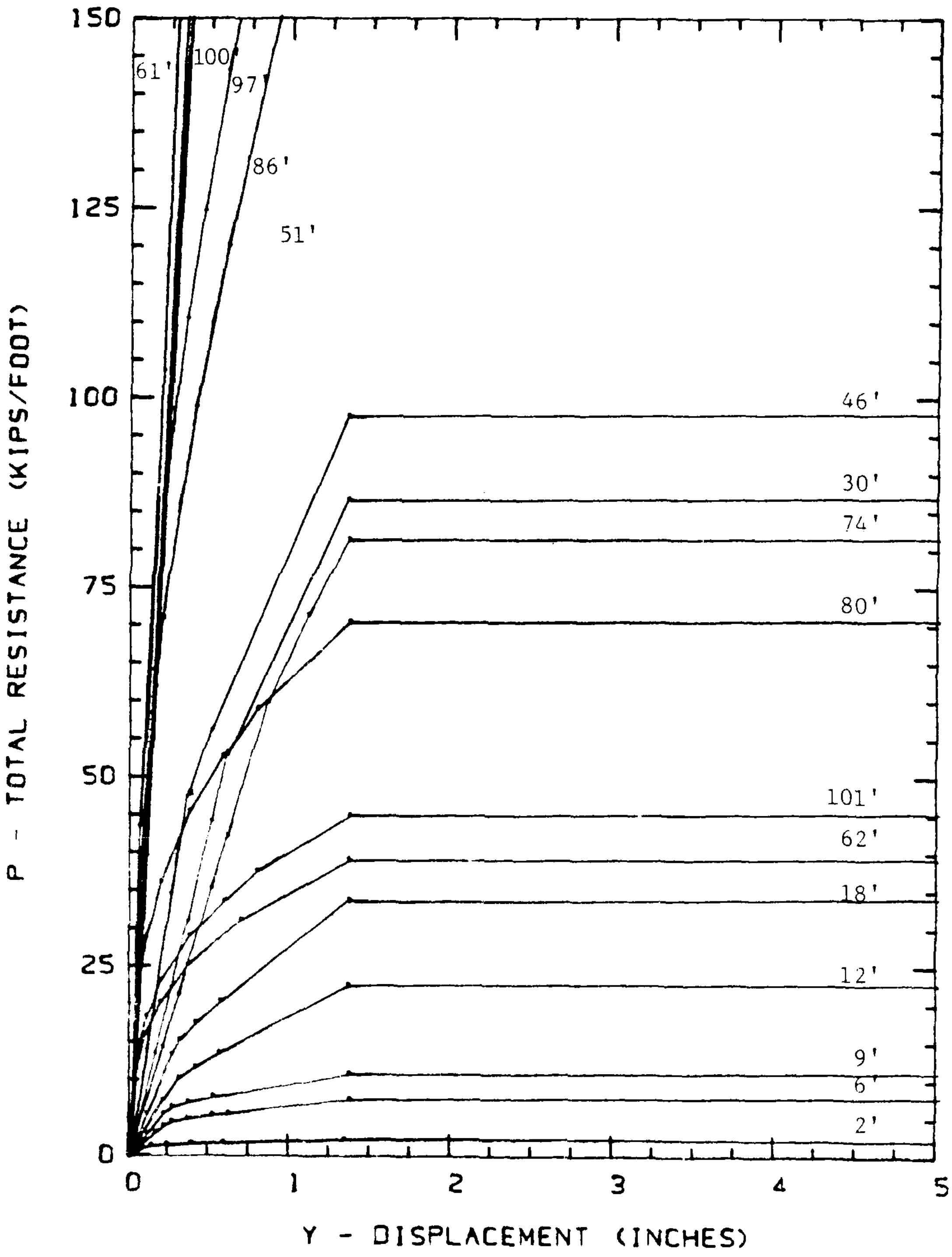
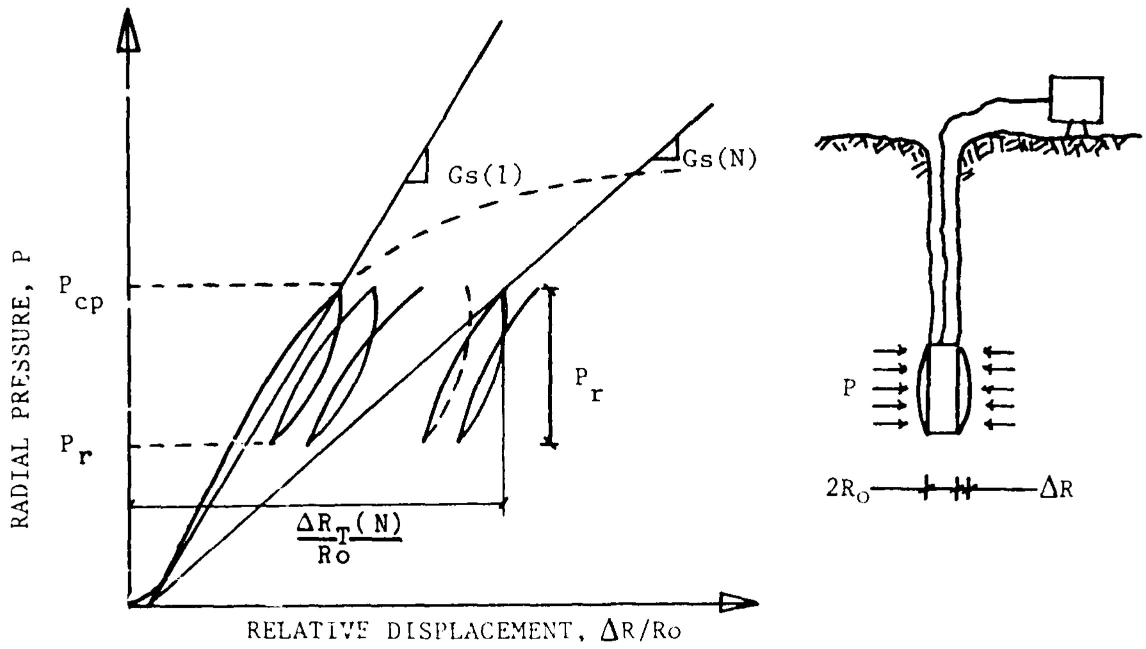



FIGURE 58. Conventionally Prepared P-y Curves for 36" R.C. Drilled Shaft (McClelland Engineers, 1986).



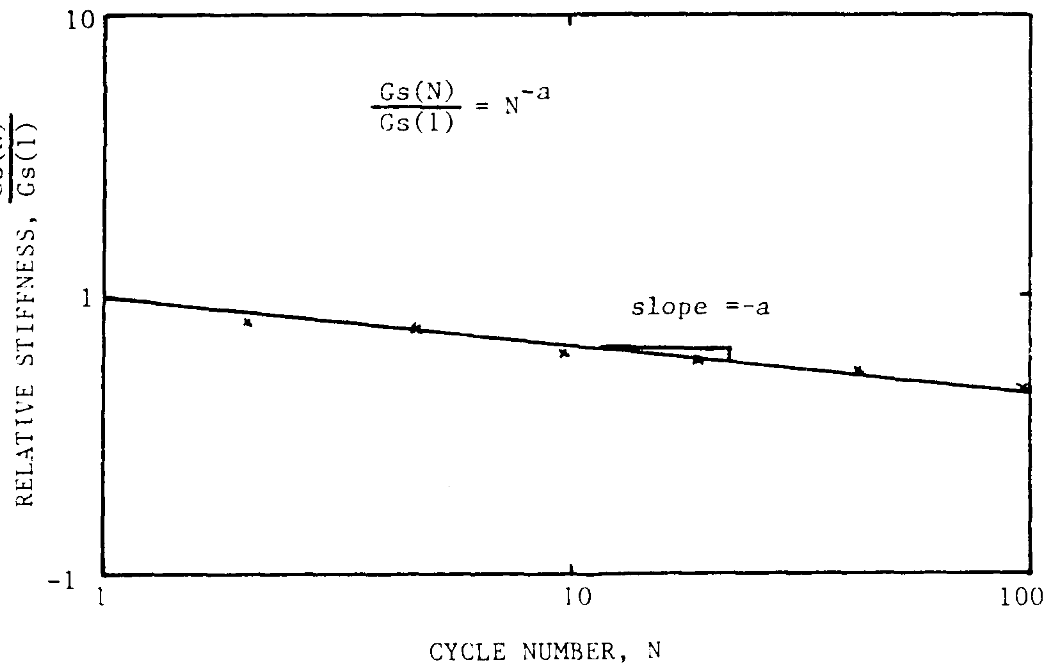




Figure 59. Definition of the Cyclic Degradation Parameter for the Secant Shear Modulus.

TABLE 4. Pressuremeter Cyclic Degradation Parameters for the Secant Shear Moduli

| PMT Test No. | PMT Type | Depth (ft) | ΔR/R (%) | a | a Average |
|---|---|---|---|---|---|
| B2-2 | PREBORED TEXAM | 2 | 12.8<br>22.4 | 0.044<br>0.038 | 0.041 |
| B1-7 | | 7 | 7.9<br>15.8 | 0.091<br>0.062 | 0.077 |
| B1-10 | | 10 | 5.8<br>16.0 | 0.086<br>0.063 | 0.075 |
| B1-15 | | 15 | 17.3 | 0.064 | 0.064 |
| B1-30 | | 30 | 13.3<br>22.0 | 0.074<br>0.056 | 0.065 |
| Overall Average | | | | | 0.064 |
| D1-2 | DRIVEN CPMT | 2 | 3.2<br>7.3 | 0.054<br>0.107 | 0.081 |
| D1-5 | | 5 | 1.2<br>5.0 | 0.115<br>0.094 | 0.105 |
| D1-9 | | 9 | 3.2<br>9.1 | 0.112<br>0.108 | 0.110 |
| D1-13 | | 13 | 3.3<br>8.6 | 0.108<br>0.109 | 0.109 |
| D1-17 | | 17 | 1.8<br>6.4 | 0.136<br>0.096 | 0.116 |
| Overall Average | | | | | 0.105 |
| B3-2 | PREBORED TEXAM | 2 | 7.6<br>13.4 | 0.056<br>0.030 | 0.043 |
| D2-2 | DRIVEN CPMT | 2 | 3.6<br>8.5 | 0.120<br>0.108 | 0.114 |

lower degradation may relate to the degree of saturation of the sand. The water table at the time of testing was located 3.5 ft below the ground surface, indicating that degradation may be greater in saturated sands than in unsaturated sands.

The average a values below the water table were fairly consistent. For prediction purposes an overall average a value was selected for each pile (see Section 6.2).

Another observation on the cyclic degradation entailed the degradation of the cyclic shear modulus as defined in

Figures 60 and 61. The $G_{C(N)}/G_{C(1)}$ versus N curves for the individual PMT tests may be found in Appendix D. The curves for the driven CPMT tests show an apparent degradation of the cyclic shear modulus during the first series of cycles.

### 5.3.3 Creep response

Near the end of each PMT test the pressure was held constant while recording the increase in volume of the probe. The results are presented graphically in Figure 62 and 63 using the same variables as employed to define creep in the piles (Section 4.4.3). For the prebored TEXAM PMT the creep exponent, n, averaged 0.006. The average n value for the driven CPMT tests was 0.011. Both values fell below the creep exponents found for the load test piles. The difference between the pile creep and the PMT creep exponents may be the result of the creep occuring in the pile material inself (Section 4.4.3).

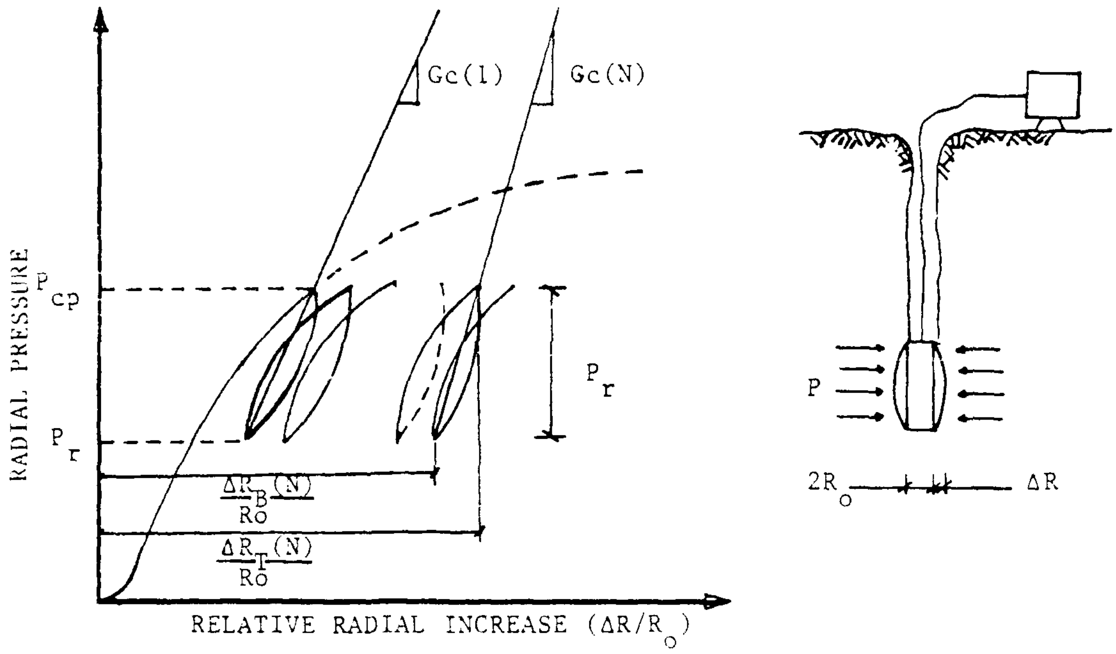



Figure 60. Definition of the Cyclic Shear Modulus.

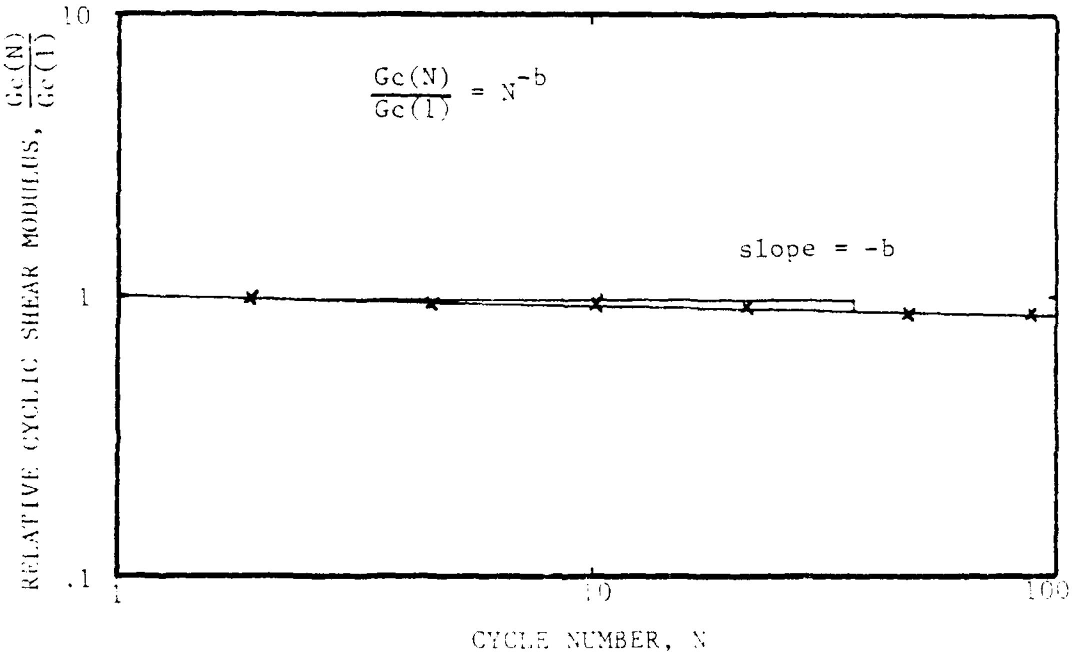
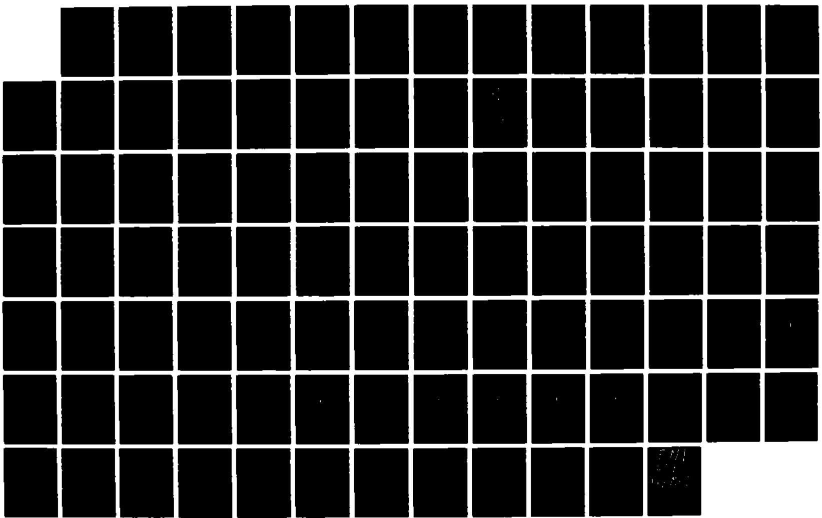
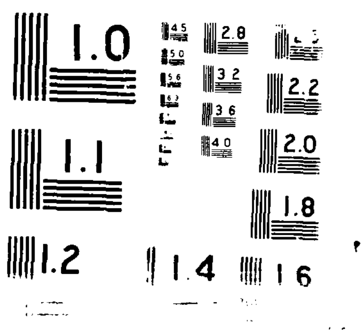



Figure 61. Definition of the Cyclic Degradation Parameter
for the Cyclic Shear Modulus.

AD-A199 115 FULL SCALE CYCLIC LATERAL LOAD TESTS ON SIX SINGLE PILES IN SAND..(U) TEXAS A AND M UNIV COLLEGE STATION DEPT OF CIVIL ENGINEERING.. R L LITTLE ET AL. AUG 88 2/2

UNCLASSIFIED TAMU-RR-5640 WES/MP/GL-88-27 F/G 13/3 NL




1.0
4.5
5.0
2.8
3.2
3.6
4.0
2.2
1.1
2.0
1.8
1.2
1.4
1.6

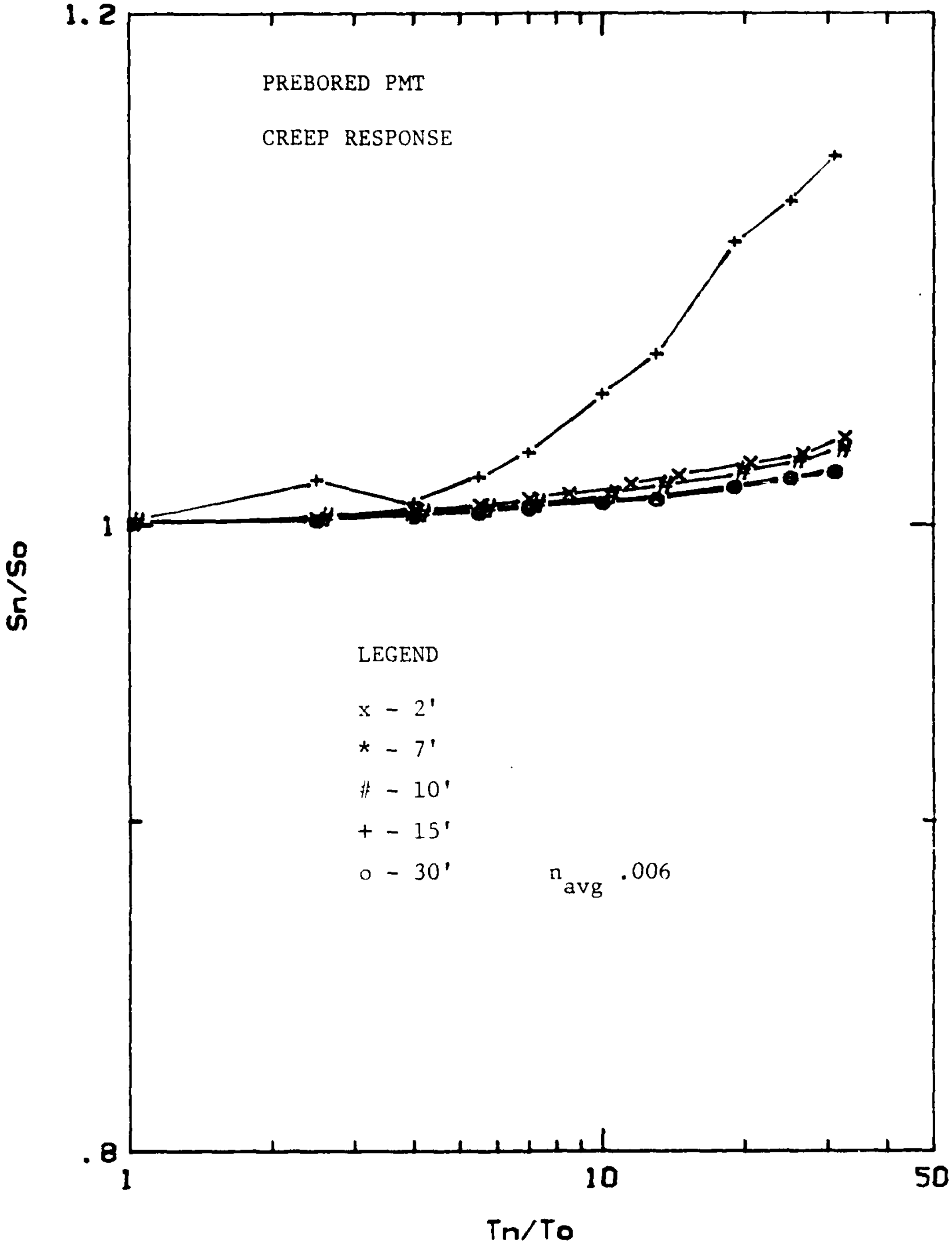



FIGURE 62. Creep Response in the Prebored PMT Tests.

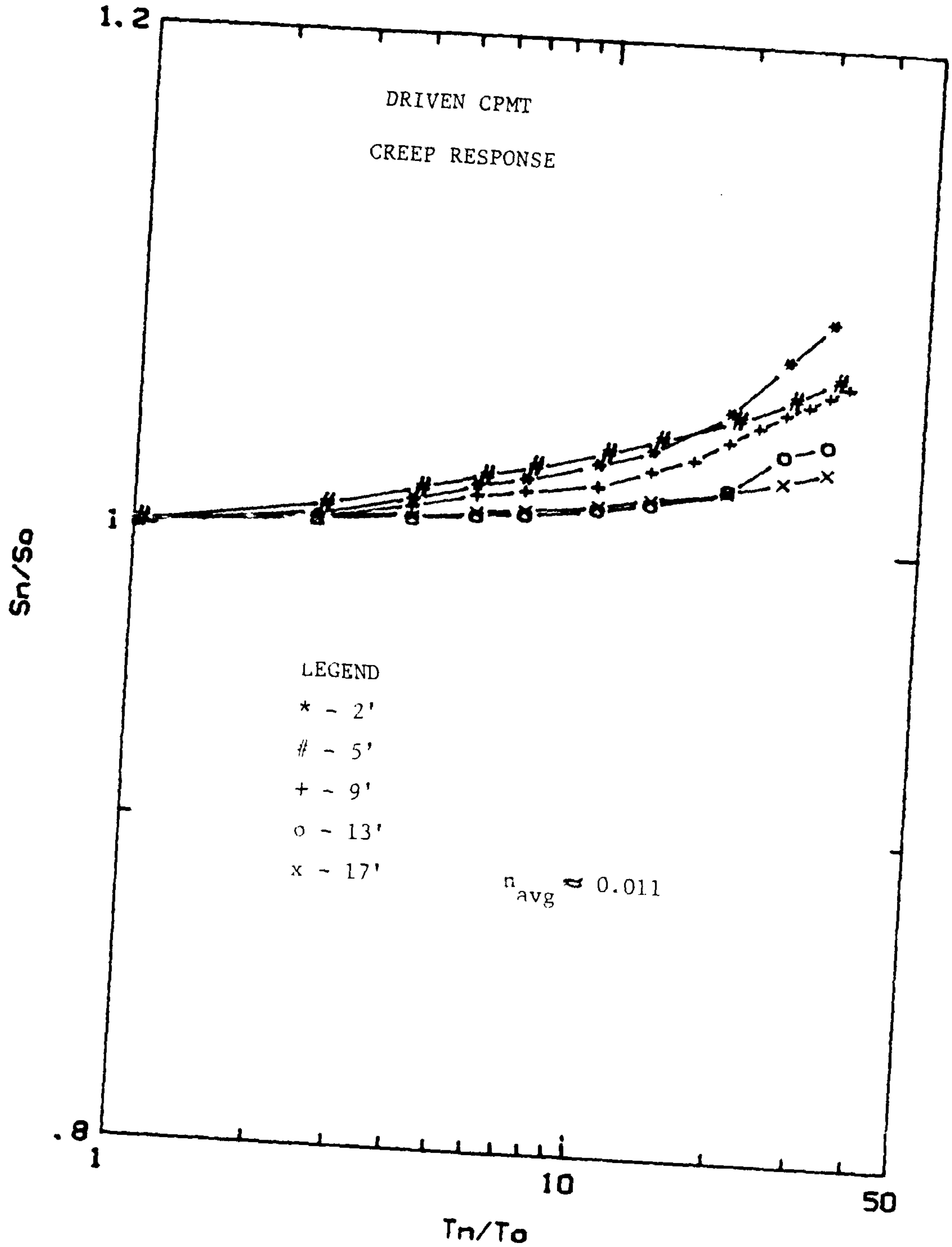



FIGURE 63. Creep Response in the Driven CPMT Tests.

# 6. COMPARISON OF PMT AND CONVENTIONAL PREDICTIONS WITH THE MEASURED RESPONSE

The approach employed in this report to predict the monotonic response of the test piles has been presented in detail in an earlier report (Little and Briaud, 1987). For the prediction of the cyclic response, the desired number of cycles is first selected, then each value of y from the monotonic P-y curve is multiplied by $N^a$ to obtain y(N). The deflection y(N) is the deflection after N cycles at the chosen level of soil resistance. The a values were selected as detailed in Section 5.3.2. This process is summarized in Figure 64 and in the following equations:

$$P(N) = P(1) \tag{2}$$

$$y(N) = y(1) \times N^a \tag{3}$$

where N = cycle number for which the P-y curve is desired,

P(1) = total soil resistance arrived at in static analysis,

P(N) = total soil resistance arrived at after N cycles,

y(1) = the static displacement at P(1),

y(N) = the displacement at P(N) after N cycles, and

a = the cyclic degradation parameter otained from the pressuremeter tests.

The cyclic P-y curves were then input as resistances into a beam-column program to obtain the predicted deflections of a pile subjected to a given set of cyclic lateral loads.

## 6.1 Monotonic Loading Response

The preboring PMT prediction yielded excellent results for the 36-in diameter drilled shaft at loads up to 40 kips (Figure 65). The conventional method predicted a much softer response. At higher loads (Figure 66), after the pile had been subjected to the series of cycles, the PMT predic-

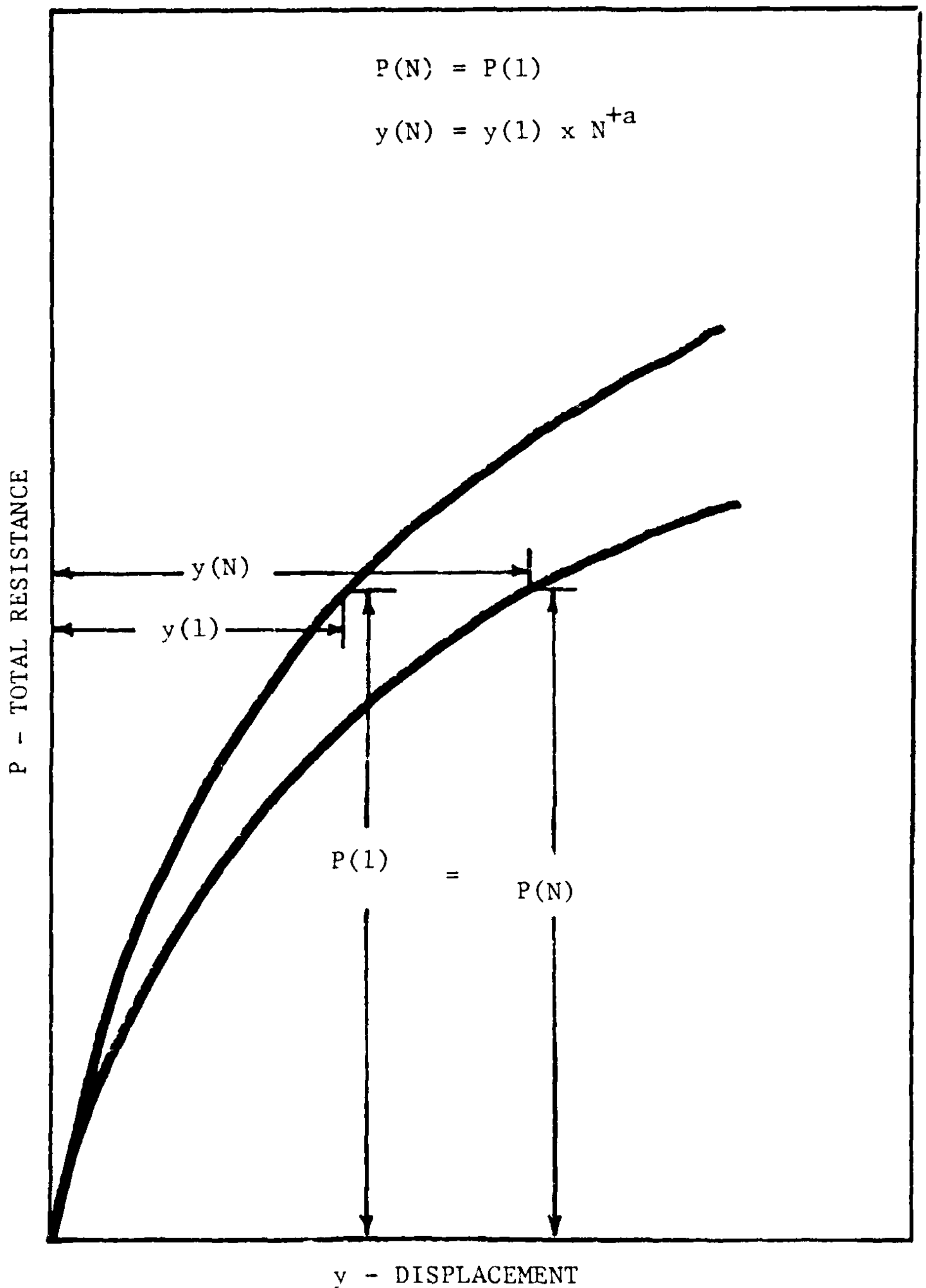



FIGURE 64. Summary of Method used to Modify a Static P-y Curve for Cyclic Predictions.

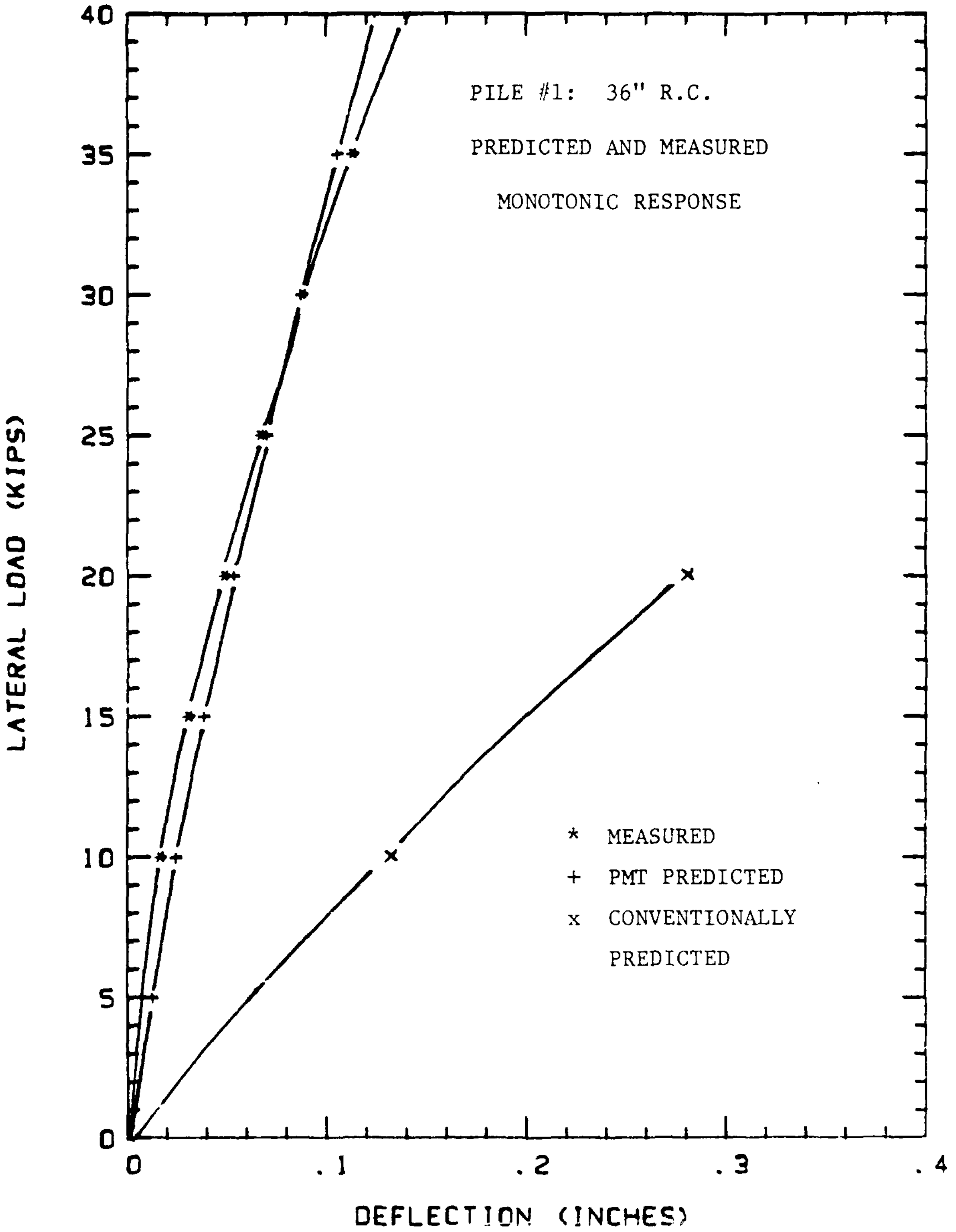



FIGURE 65. Comparison of PMT Predicted, Conventionally Predicted, and Measured Response for Pile No. 1 under Monotonic Loading, 0 to 40 KIP Scale.

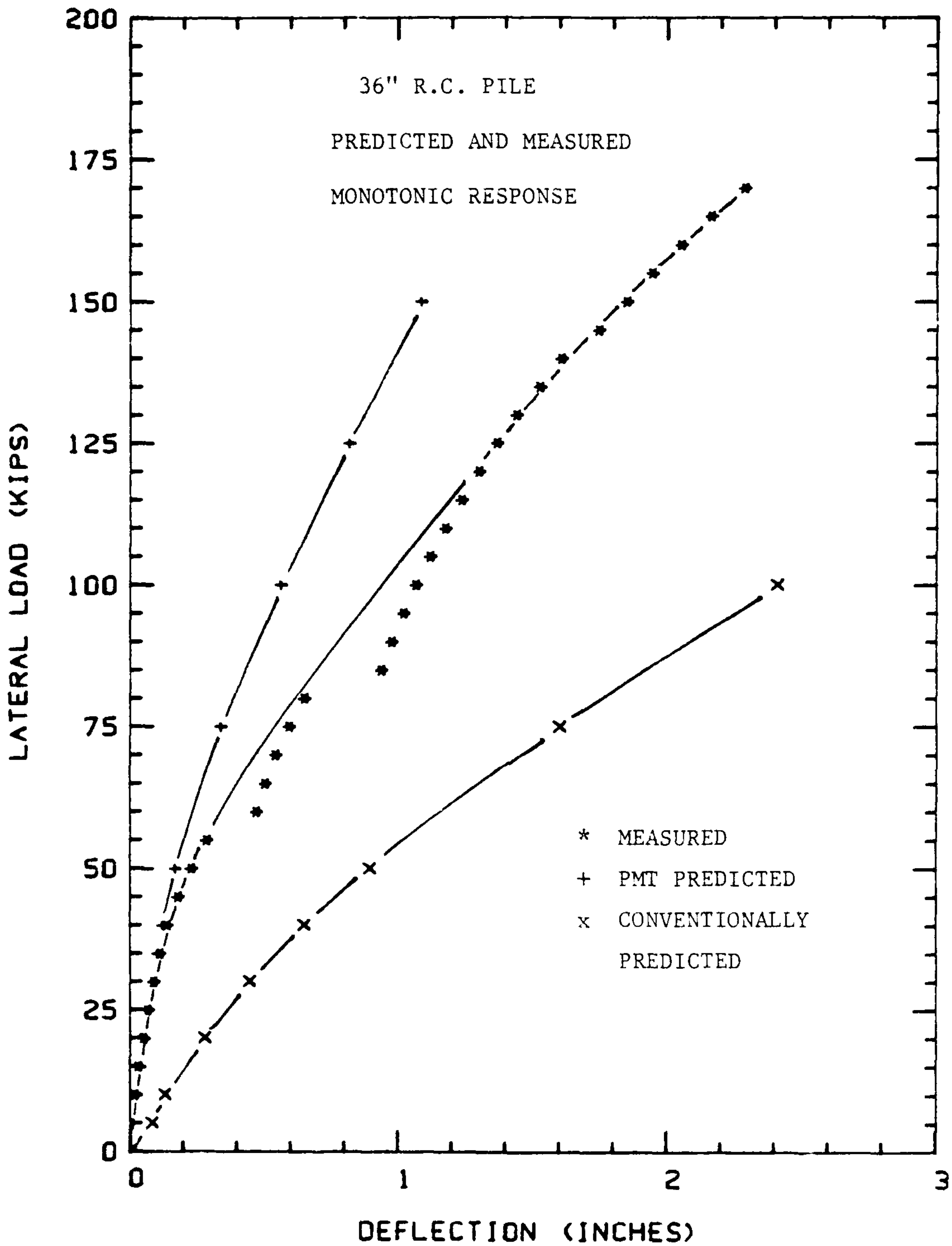



FIGURE 66. Comparison of PMT Predicted, Conventionally Predicted, and Measured Response for Pile No. 1 under Monotonic Loading, 0 to 200 KIP Scale.

tion was stiffer than the measured results. This is probably due to the fact that the cycles induce accentuated curvature in the monotonic envelope and that the flexural stiffness of the pile decreases with increasing load and with increasing number of cycles due to crack propagation. This deterioration was not modeled in the prediction process.

The predicted response for the pipe pile using the preboring PMT and assuming the pile was a non-displacement pile gave excellent results throughout the range of lateral loads applied (Figures 67 and 68). The steel pipe was not subject to the same magnitude of stiffness deterioration as the concrete drilled shafts. At high load levels, after the series of cycles, the PMT method slightly underpredicted the pile displacement. The conventional method, on the other hand, significantly overpredicts the displacements throughout the range of loads applied to the pile.

The square concrete pile was modeled with both the driven CPMT and prebored PMT test results. Both methods produced excellent predictions for loads up to 40 kips (Figure 69). At higher loads the prebored PMT predictions closely followed the measured results until after the second cycling series (Figure 70). It is likely that the deterioration of the pile stiffness (EI-value) associated with cycling was not a factor in the pile-soil response until the effects of the prestressing in the pile were overcome. Therefore, the envelope on measured results up to the second series of cycles probably is an accurate reflection of the soil response alone. The driven CPMT predictions overestimated the pile-soil stiffness response at high loads.

For the three 42-in diameter drilled shafts the pressuremeter method predicted a softer initial response at loads below 30 kips and a stiffer response at load levels over 50 kips (Figures 71 and 72). A partial reason for the predictions of the 42-in diameter drilled shafts not being

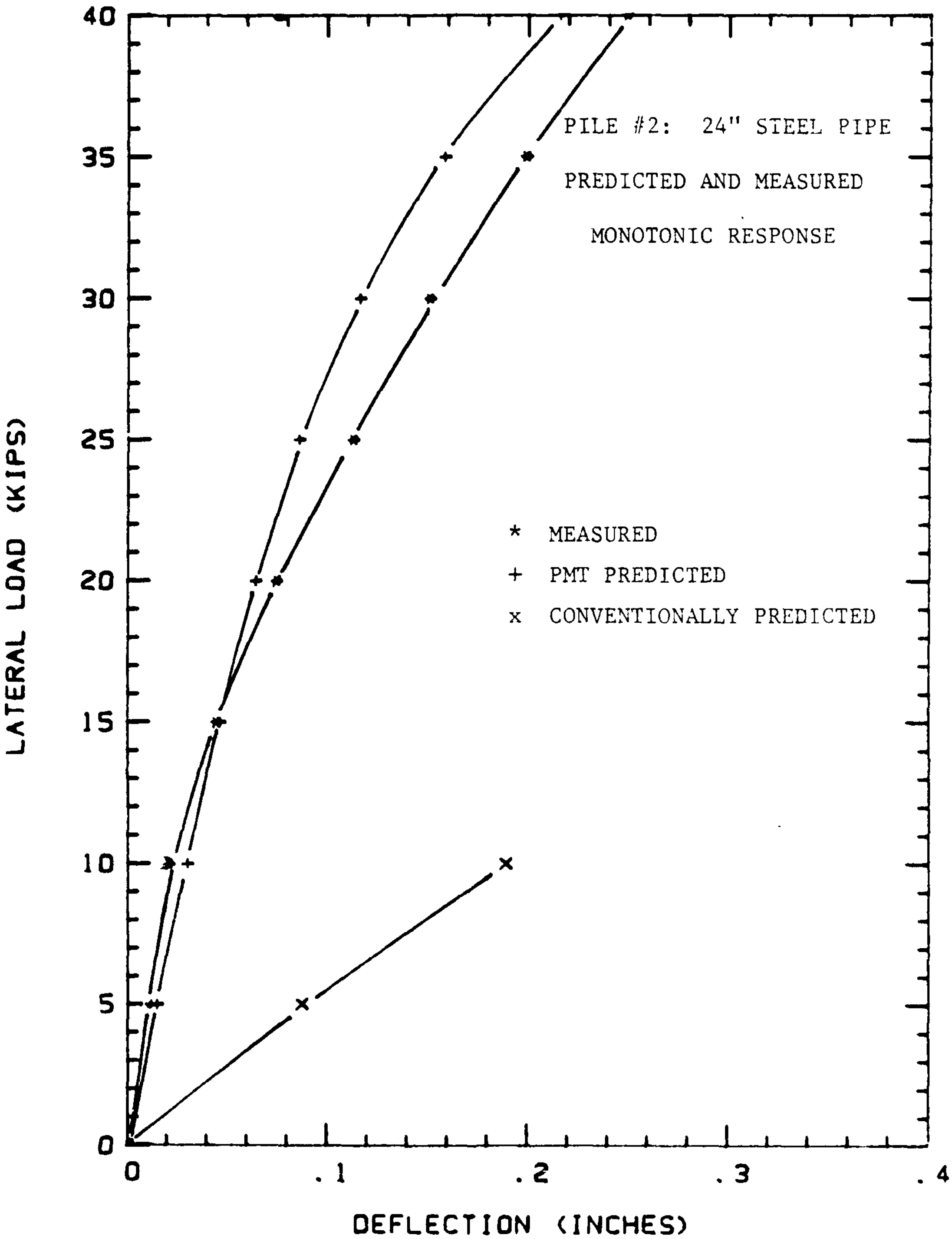



FIGURE 67. Comparison of PMT Predicted, Conventionally Predicted, and Measured Response for Pile No. 2 under Monotonic Loading, 0 to 40 KIP Scale.

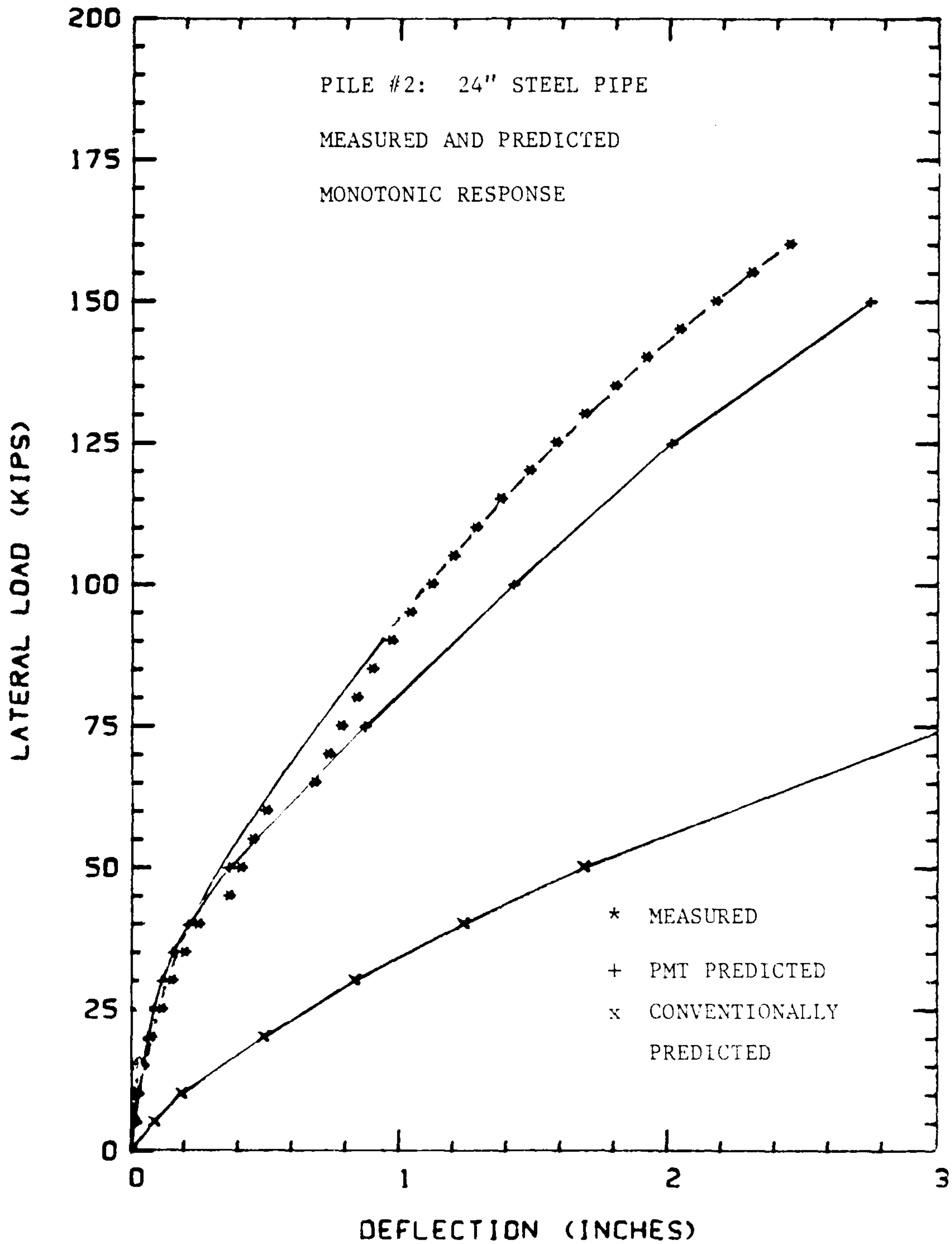



FIGURE 68. Comparison of Predicted, Conventionally Predicted, and Measured Response for Pile No. 2 under Monotonic Loading, 0 to 200 KIP Scale.

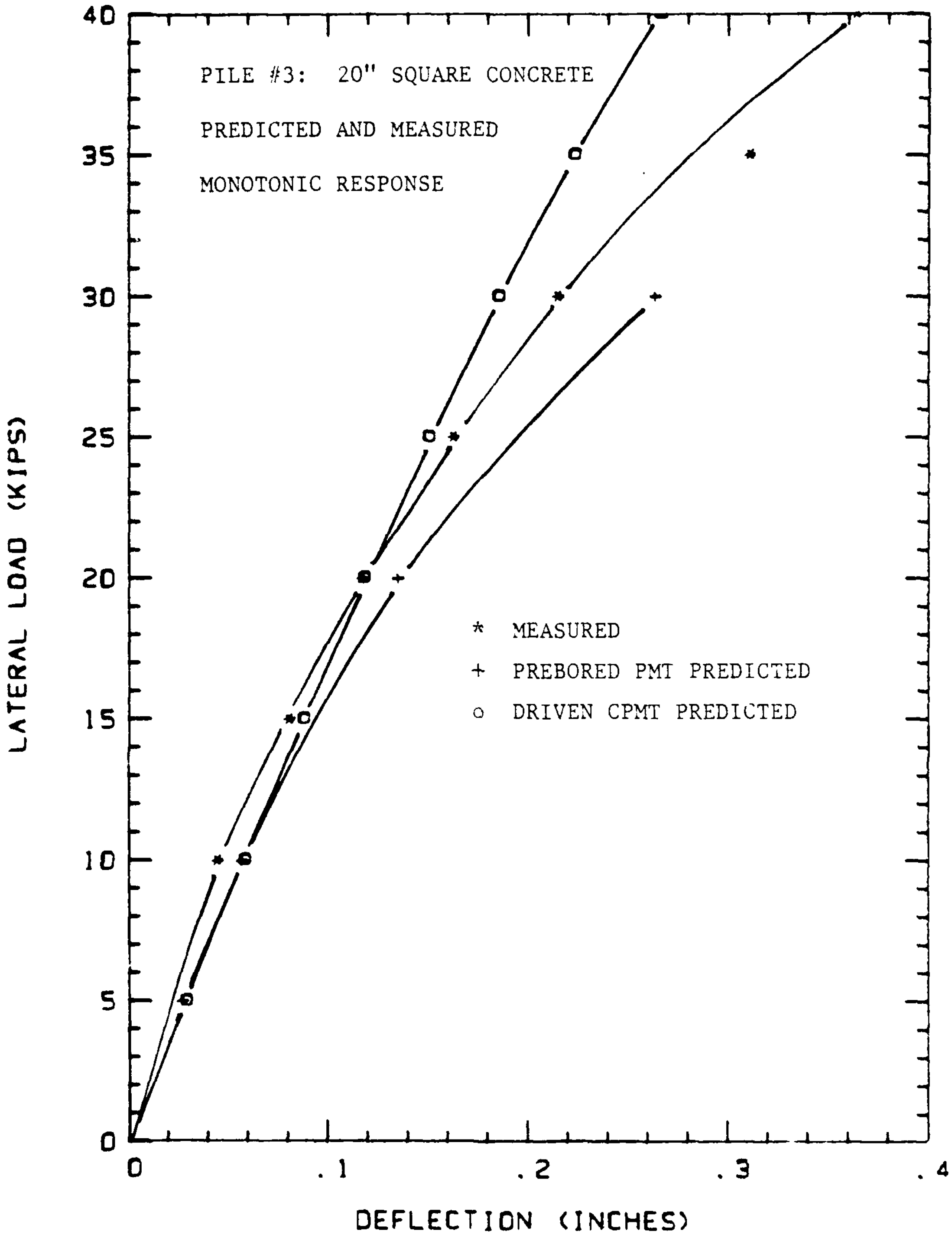



FIGURE 69. Comparison of Measured and PMT Predicted Monotonic Responses for Pile No. 3, 0 to 40 kip Scale.

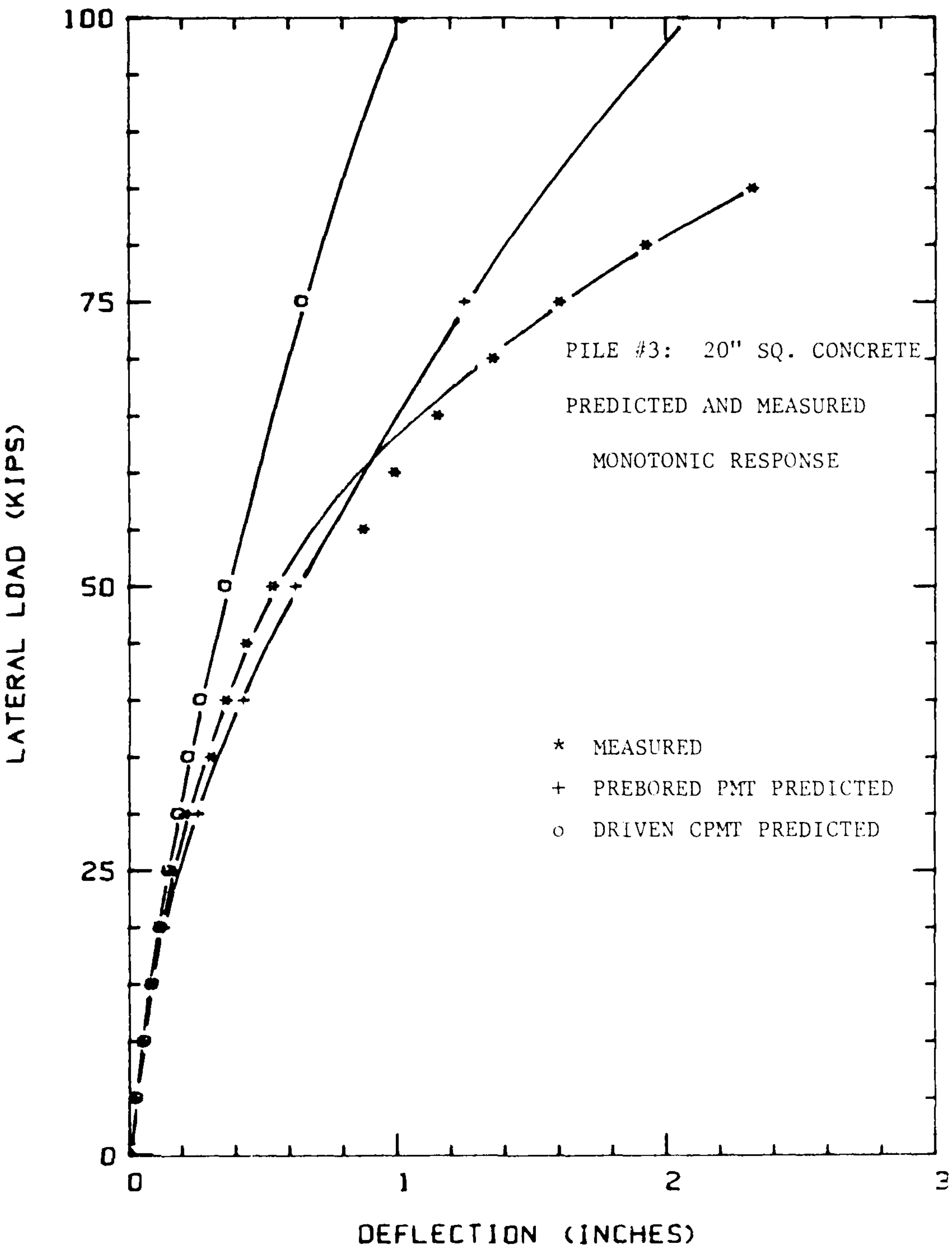



FIGURE 70. Comparison of Measured and PMT Predicted Monotonic Responses for Pile No. 3, 0 to 100 KIP Scale.

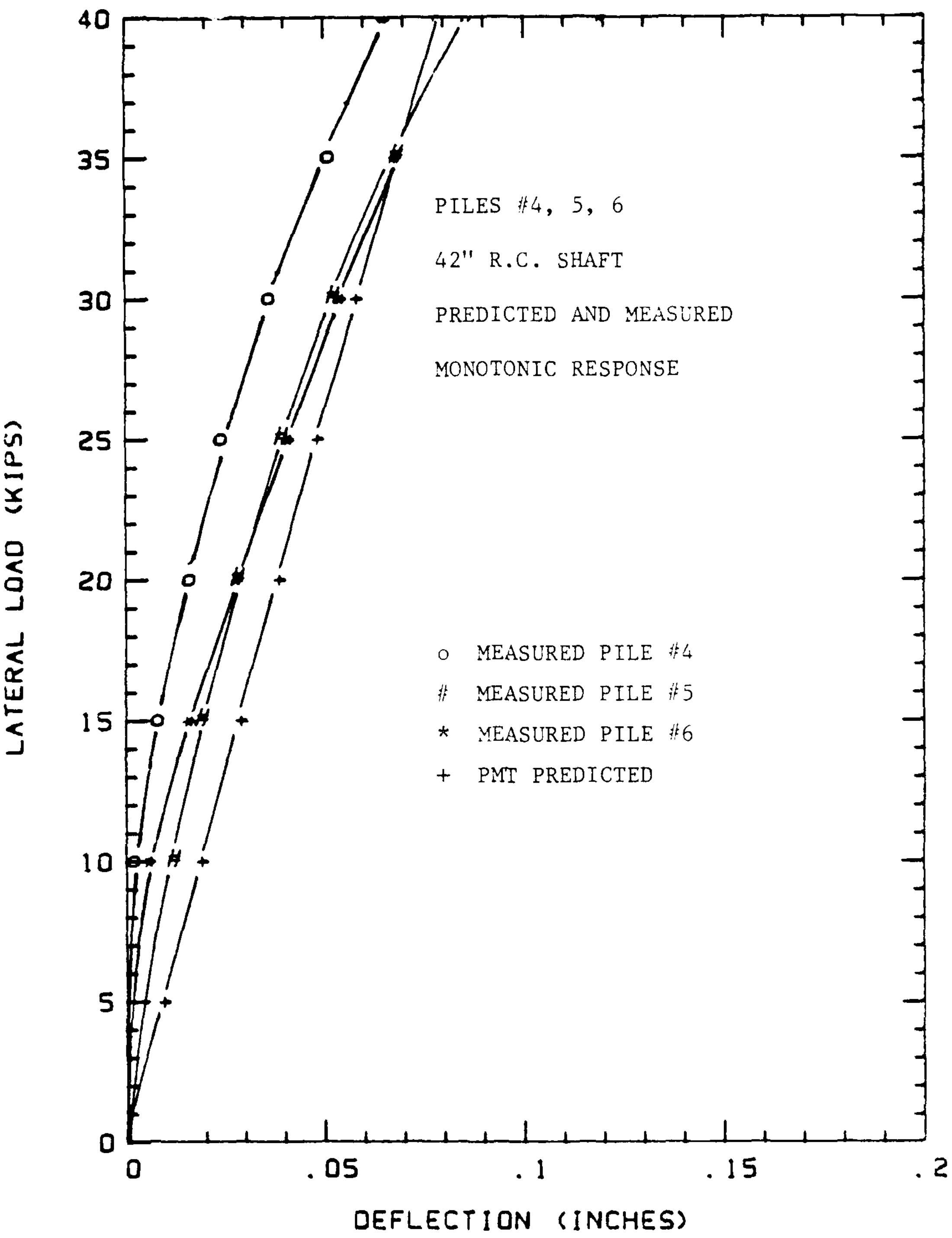



FIGURE 71 Comparison of Measured to PMT Predicted Monotonic Response for Pile Nos. 4, 5, and 6, 0 to 40 KIP Scale.

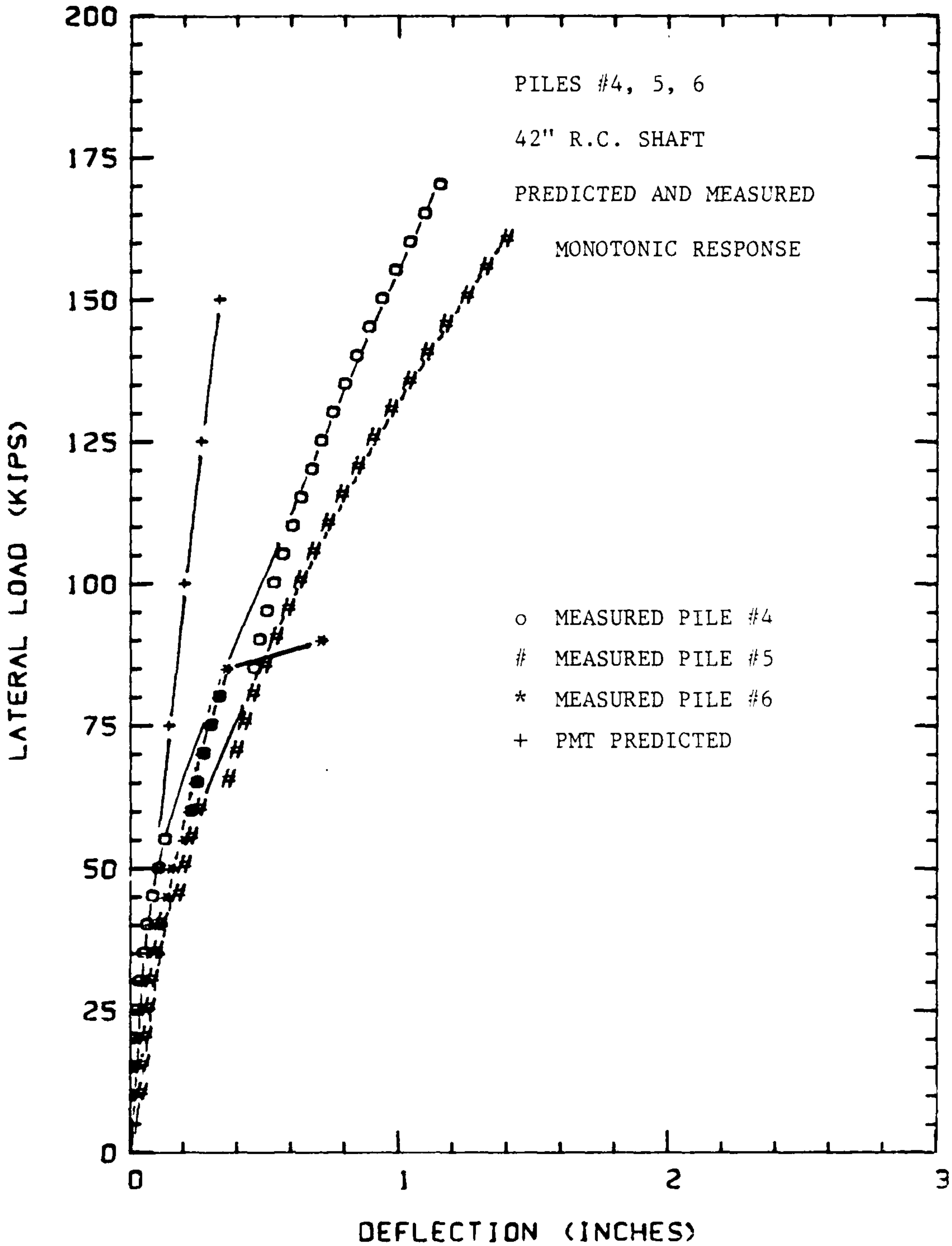



FIGURE 72. Comparison of Measured to PMT Predicted Monotonic Response for Pile Nos. 4, 5, and 6, 0 to 200 KIP Scale.

as good as the predictions for the other piles is the difficulty encountered in determining the correct pile stiffness to incorporate into the pile-soil stiffness model. As explained in Section 3, these shafts were used as reaction shafts during the previously performed vertical load tests. As such, they were subjected to extreme axial tension stresses. Although in the prediction method a reduced pile stiffness (EI-value) was assumed, it may not have been an accurate model of the actual piles. Judging from the excellent results in predicting the response of the other piles in this study, the less satisfactory results for the 42-in diameter drilled shafts must be due to inaccuracies in modelling the pile itself, and not in modeling the soil response.

### 6.2 Cyclic Loading Response

The predictions of the cyclic response of the test piles using the results of the cyclic PMT tests are shown in Figures 73 through 77. The predictions are presented as cyclic envelopes. For any given load level the $N^{th}$ cyclic envelope represents the deflection expected after N cycles at that load level.

The cyclic prediction for the square prestressed concrete pile was obtained from both the preboring and the driven CPMT results. The cyclic predictions for the steel pipe pile and the drilled shafts were obtained from the preboring PMT only.

Table 5 summarizes the cyclic predictions and compares them to the measured responses. In each case, the predicted increase in deflection is less than the measured increase. Four possible reasons for the PMT method underpredicting the cyclic degradation are: (1) the difference in confinement between the pile and the PMT probe, (2) load-control cyclic pile load tests may not cause exclusively load-control cyclic loading of each soil strata, (3) influence of previ-

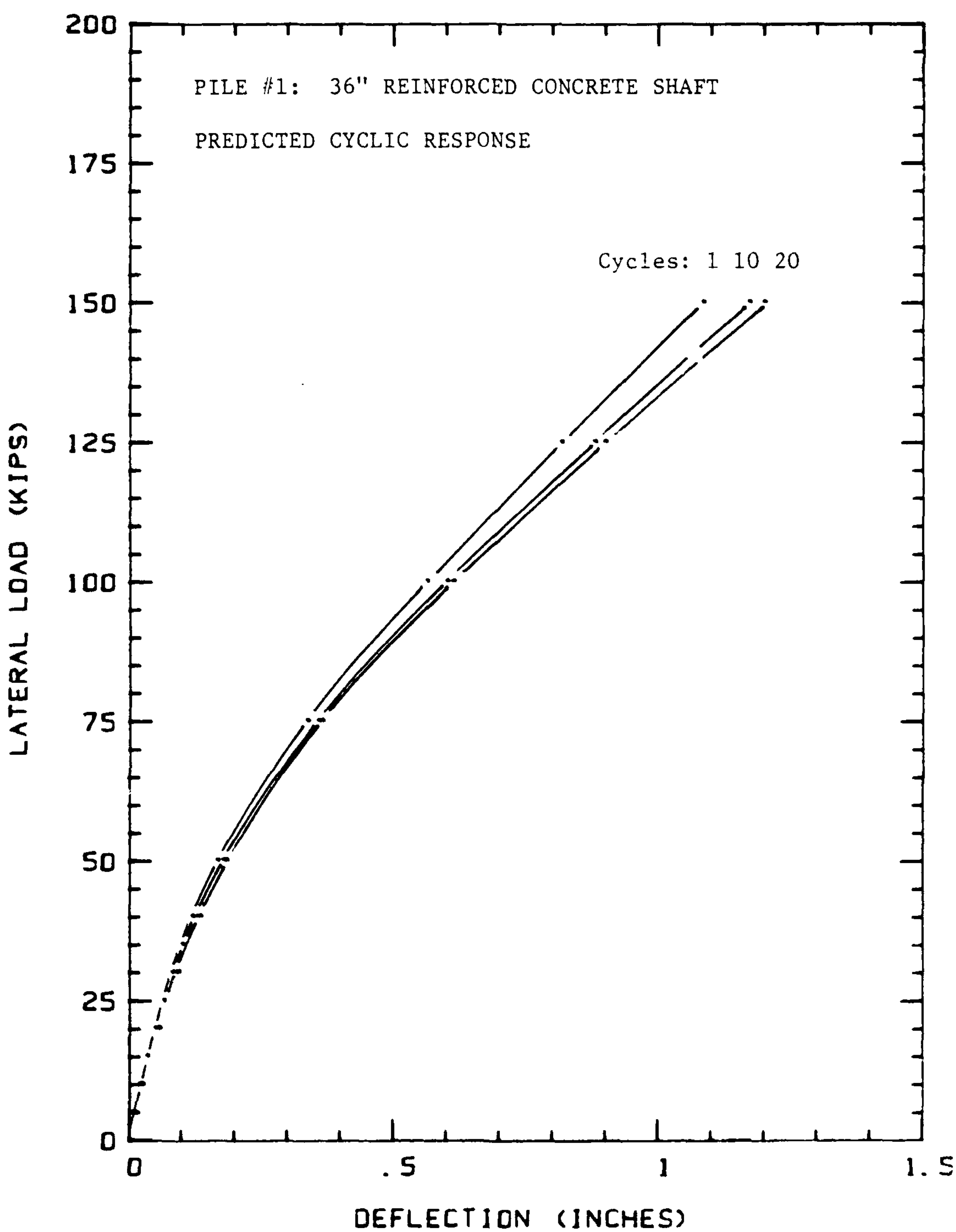



FIGURE 73. Prebored PMT Predicted Cyclic Response, Pile No. 1.

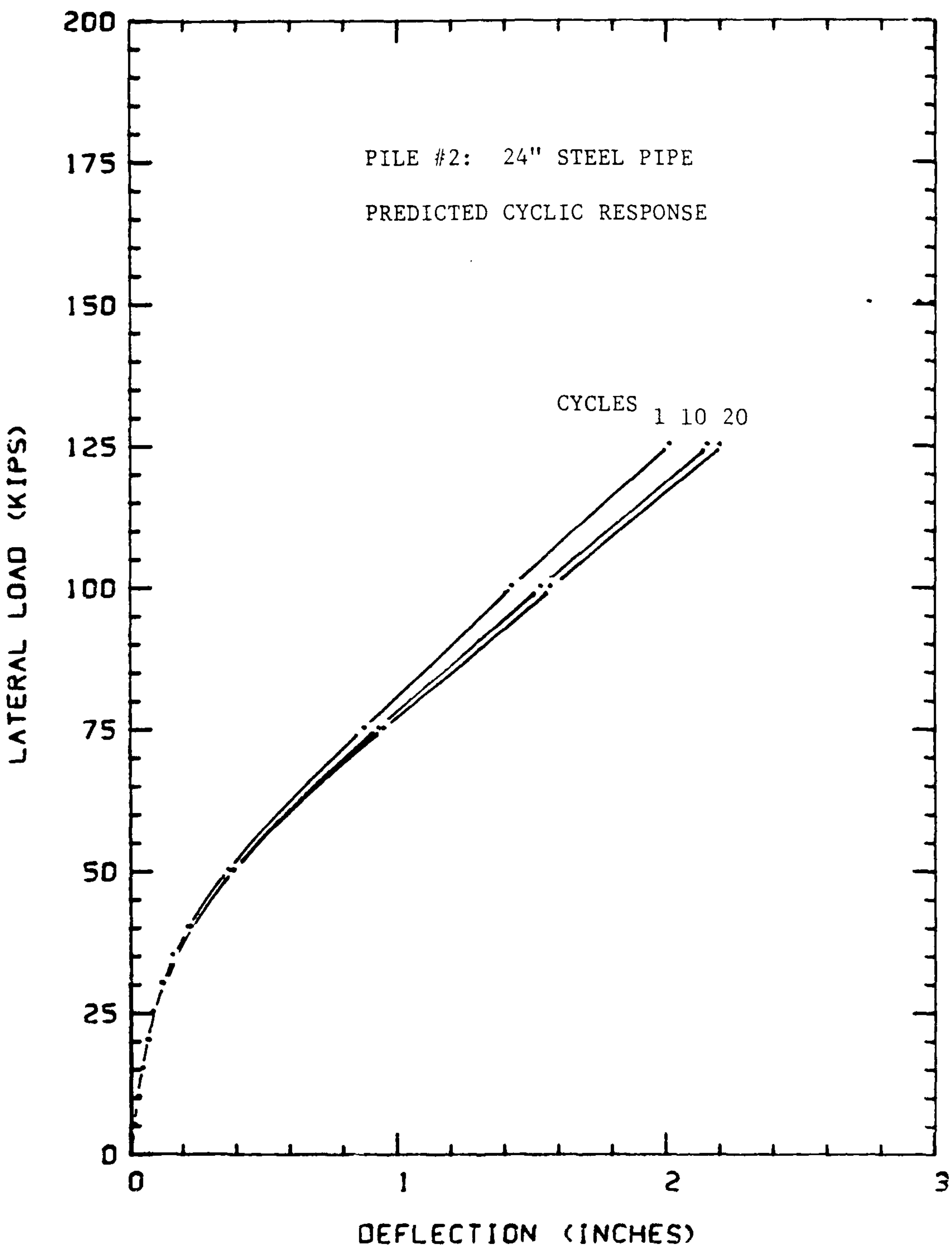



FIGURE 74. PMT Predicted Cyclic Response, Pile 2.

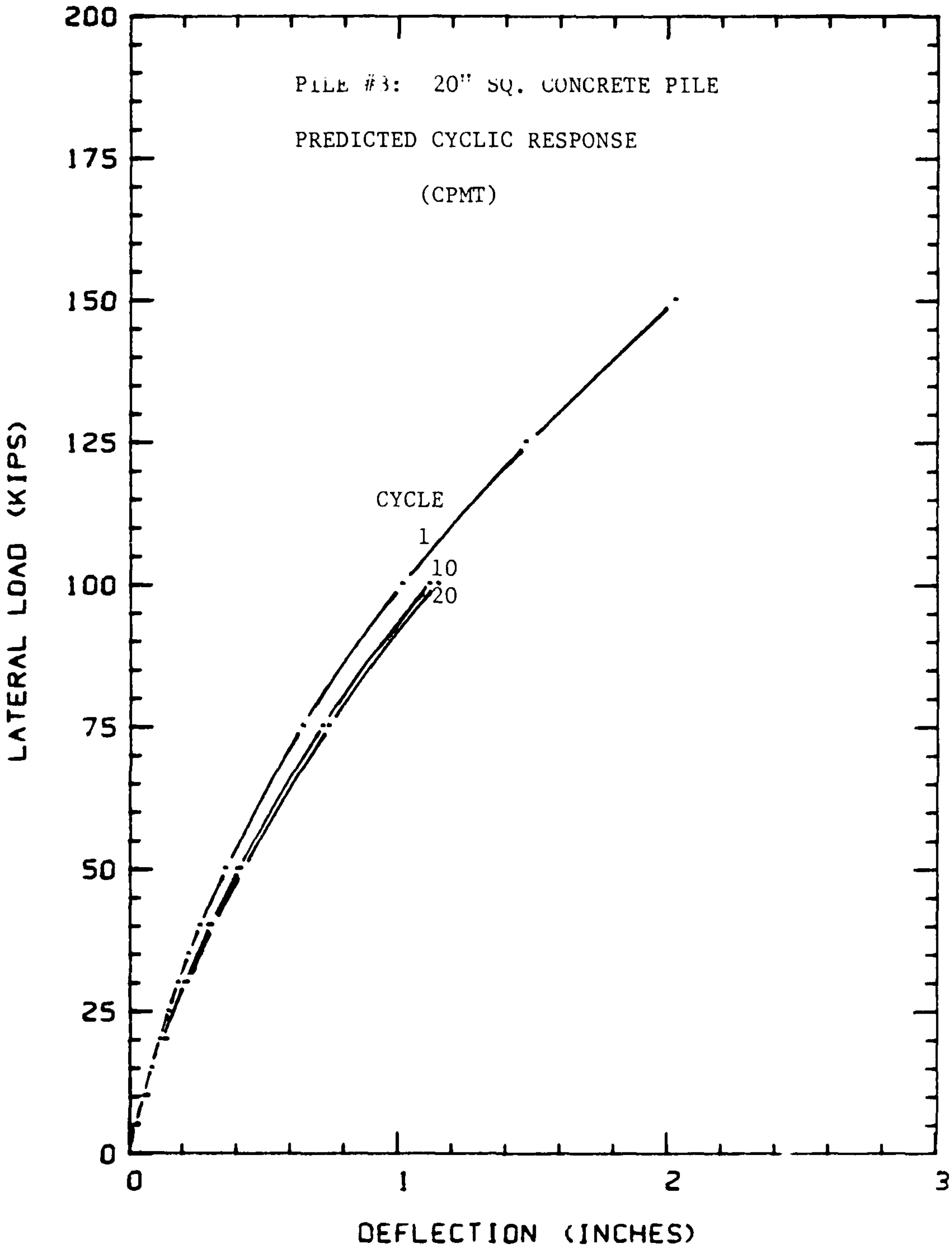



FIGURE 75. Driven CPMT Precicted Cyclic Response, Pile #3.

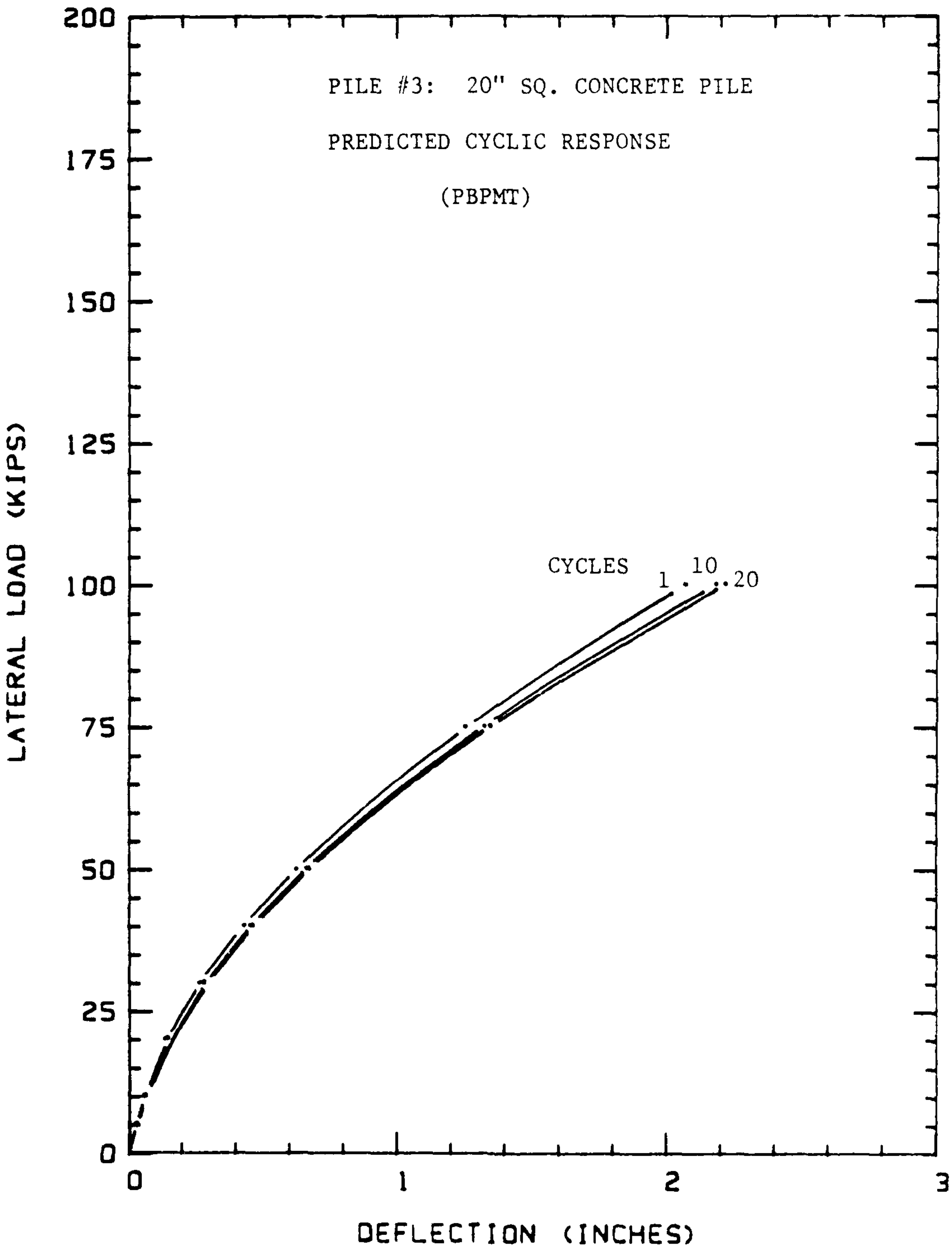



FIGURE 76. Prebored PMT Predicted Cyclic Response, Pile #3.

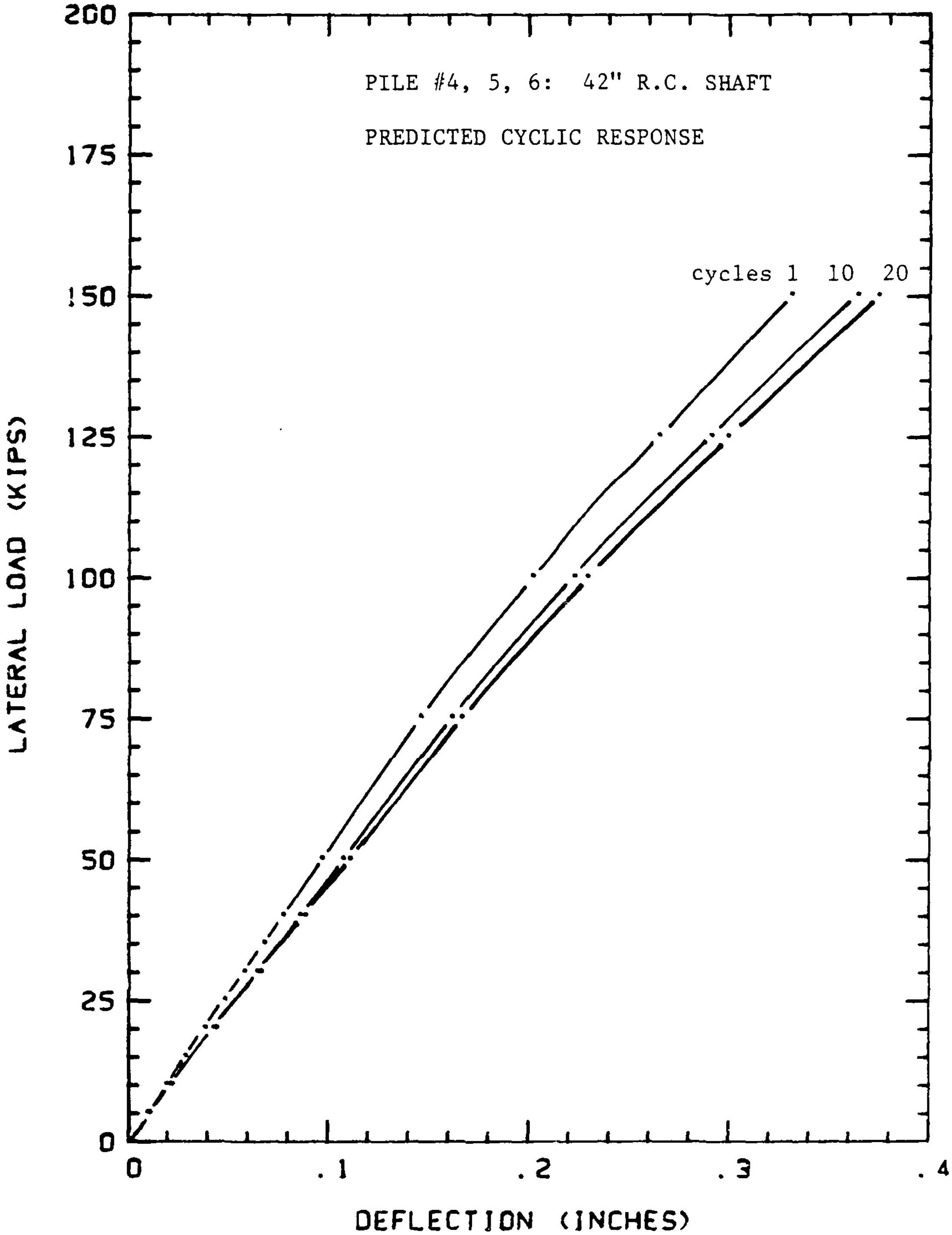



FIGURE 77. Prebored PMT Predicted Cyclic Response, Pile Nos. 4, 5, and 6.

TABLE 5. Comparison of Percent Increase in Deflection with Cycling: Predicted and Measured

| Pile ID No. | Pile Description | Cyclic Load Level (kips) | % Increase in Deflection | | | |
|---|---|---|---|---|---|---|
| | | | After 10 Cycles | | After 20 Cycles | |
| | | | Measured | Predicted | Measured | Predicted |
| 1 | 36" Drilled Shaft | 55 | 51.1 | 8.5 | 66.9 | 11.6 |
| | | 80 | 17.9 | 7.6 | 35.4 | 10.3 |
| 2 | 24" Pipe Pile | 40 | 24.9 | 4.5 | 34.1 | 5.8 |
| | | 60 | 15.2 | 4.2 | 25.9 | 7.9 |
| 3 | 20" Square Concrete | 30 | 22.3 | 5.5 | 27.9 | 7.2 |
| | | 50 | 26.4 | 6.0 | 43.1 | 7.9 |
| 4 | 42" Drilled Shaft | 55 | 55.4 | 10.8 | 72.7 | 14.5 |
| | | 80 | 17.8 | 10.5 | 28.3 | 14.1 |
| 5 | 42" Drilled Shaft | 40 | 41.7 | 11.0 | 56.0 | 14.5 |
| | | 60 | 19.5 | 10.6 | 34.1 | 14.5 |
| 6 | 42" Drilled Shaft | 30 | 48.1 | 10.5 | 79.6 | 14.5 |
| | | 50 | 11.5 | 11.0 | 17.9 | 14.5 |
| | Averages | | 29.3 | 9.0 | 43.5 | 12.2 |

ous series of cycles on subsequent series of cycles during a test and (4) degradation of the pile flexural stiffness during cyclic loading.

There is a difference in confinement between the pile and the PMT probe; this is shown in Figure 78. During the lateral movement of a pile, the soil is able to move towards the back of the pile where a gap is opening. During a PMT test, the soil is displaced radially outward. Under monotonic loading, the difference in confinement may not significantly affect the pile-pressuremeter probe analogy. Under repeated cyclic loading, however, the difference in confinement may result in significantly greater degradation in the soil resistance against the pile than against the pressuremeter probe.

Another possible explanation for the pressuremeter predicting less degradation under cyclic loading may arise from the mode of cycling experienced by the soil during the cyclic lateral loading of a pile. In earlier studies (Makarim and Briaud, 1986; Little and Briaud, 1987) it has

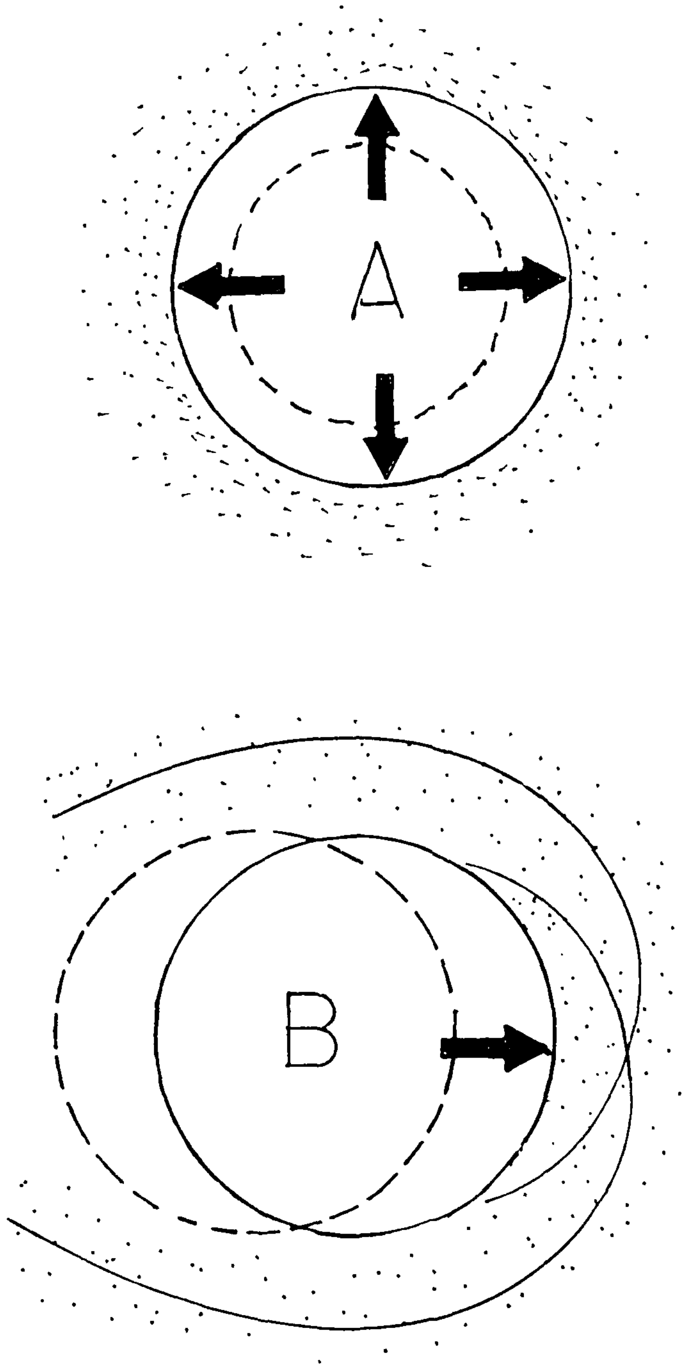



FIGURE 78. Difference in Confinement between the PMT Probe Expansion (A) and the Lateral Movement of a Pile (B).

been shown that for pressuremeter tests the soil resistance degrades more rapidly under displacement-controlled conditions than under pressure-controlled conditions. In this study, pressure-controlled cyclic pressuremeter tests were used to predict the soil resistance degradation for the load-controlled cyclic pile load tests. In reality, each soil layer may not be subjected <u>exclusively</u> to load-controlled conditions during a pile load test. The actual loading conditions on the soil may lie somewhere between pressure-control and displacement-control, making the pressure-control-predicted response the most conservative. It is recommended that future pressuremeter predictions be based on a combination of two cycling modes. One possible method may be to perform 10 cycles load-controlled and then 10 cycles displacement-controlled during the pressuremeter tests and calculate the degradation exponent for each mode of cyclic loading.

The influence of the first series of cycles on the soil response during subsequent cycles may also have affected the comparison between predicted and measured results. The first series of cycles in a test is more likely to be influenced by seating problems than subsequent series of cycles.

Particularly damaging to the prediction process employed in this study was the degradation of the pile flexural stiffness associated with cyclic loading. The deterioration of pile stiffness had a profound effect on the concrete piles studied in this report. This can be seen by comparing the measured increase in deflection after 20 cycles on concrete pile 4 at a load of 55 kips with the increase in deflection for concrete pile 5 at a load of 60 kips. The increase is 72.7% for pile 4 and 34.1% for pile 5. The piles were designed and constructed using identical procedures, and since they were installed within the same soil strata it would be logical to assume that the response of

the soil during the series of cycles would be nearly the same. The explanation for the large variation in response between the two identical piles lies in the relative degradation of their flexural stiffnesses.

The primary mechanism for reduction of the pile flexural stiffness was the propagation of cracks through the concrete cross-section during cycling. Increased cracking reduced the strength of the concrete. Crack propagation was most pronounced during the first cycling series for each of the reinforced concrete drilled shafts. After the concrete had suffered significant cracking during the first cycling series, the pile stiffness would tend toward a limit value since the stiffness would primarily be related to the strength of the steel reinforcement. Therefore, the difference mentioned above exists because pile 4 was being cycled for the first time while pile 5 was being cycled for the second time.

An alternative method for using the pressuremter results to predict the pile responses would be to treat the pressuremeter tests as a model pile load test and apply the PMT degradation parameter a directly to the monotonic prediction:

$$y(N) = y(1) \times N^{a} \qquad (4)$$

$$H(N) = H(1) \qquad (5)$$

where $y(N)$ = pile deflection at the groundline after N cycles at load H,

$y(1)$ = pile deflection at the groundline after monotonic load H,

$a$ = average PMT degradation parameter,

$H(N)$ = horizontal load applied at the top of the $N^{th}$ cycle,

$H(1)$ = horizontal load applied at the top of the $1^{st}$ cycle,

$N$ = number of cycles.

The accuracy of this prediction method for the relatively homogeneous strata and piles in this study may be judged by comparing the measured average a values with the PMT predicted average of 0.064 (Table 6). This alternative method yielded excellent agreement between predicted average and measured average a values for the piles expected to have the least deterioration in pile stiffness, namely the steel pipe pile (a = 0.062) and the prestressed concrete pile (a = 0.063). The reinforced concrete drilled shafts, on the other hand, showed greater cyclic degradation than predicted (a values of 0.086, 0.080, 0.073 and 0.068 for piles 1,4,5 and 6, respectively).

TABLE 6. Comparison of Measured and Predicted Secant Shear Modulus Cyclic Degradation Parameters

| Pile No. | Measured $a_{average}$ | Predicted $a_{average}$ |
|---|---|---|
| 1 | 0.086 | |
| 2 | 0.062 | |
| 3 | 0.063 | 0.064 |
| 4 | 0.080 | |
| 5 | 0.073 | |
| 6 | 0.068 | |
| Overall Average | 0.072 | 0.064 |

**6.3 Comparison of Creep Exponents**

In Section 5.3.3 it was shown that the PMT creep exponents were 0.006 for the TEXAM preboring PMT tests and 0.011 for the driven CPMT tests. These exponents were lower than the exponents backcalculated from the pile load tests since these exponents stabilized around 0.015 to 0.02. The disrepancy may be the result of two of the same mechanisms cited for the underprediction of cyclic degradation, namely the difference in confinement between the pile and the pressuremeter probe and the creep of the pile flexural stiffness under a sustained load.

## CONCLUSIONS AND RECOMMENDATIONS

The main conclusions to be gathered from this study are the following:

- The four drilled shafts exhibited significantly more cyclic degradation during the first series of cycles than during the second series. This may be due to two things. First, the pile stiffness may degrade due to crack propagation from the cycling. By the second series of cycles, the pile stiffness is mainly obtained from the steel reinforcement which will not exhibit much degradation. This is thought to be the major cause. Second, the sand is densified by the first series of cycling, causing a stiffening of the response in the second series.

- The steel pipe pile showed a somewhat stiffer response during the second cyclic series than in the first. Since the stiffness of the steel should experience little or no degradation at these low load levels, the increase in stiffness is probably due entirely to the stiffening of the soil due to previous cyclic loads.

- The prestressed concrete pile showed more degradation of stiffness during the second cyclic series than in the first. This is thought to be caused by a postponement of cracking of the concrete due to the prestressing of the pile. The bending moment in the pile at the lower cyclic load level was not enough to cause tension cracks in the concrete. However, at the second, higher, cyclic load level, the effect of the prestressing was overcome and tension cracks began to form, thus reducing the pile stiffness.

- The cyclic degradation parameter, "a", values for cycles which unloaded to zero load were 53% higher

than for cycles which unloaded only to one-half the top cyclic load.

- The creep exponent, "n", values for all the piles except the prestressed concrete pile exhibited the same behavior. The n values started between 0.05 and 0.075 then reduced and stabilized between 0.015 and 0.02. For the 42-in diameter drilled shaft which failed, the n values showed an upward turn towards the end of the test indicative of the impending failure. The n values for the prestressed concrete pile began around 0.015 then increased during the test, reaching a critical load at about 90 kips. This may be due to creep in the concrete as the effect of the prestressing is overcome.

- The prediction of the monotonic loading curves by the pressuremeter method (Little and Briaud, 1987) was very good for all piles in the working load range based on the prebored PMT test data. As the loads increased, the measured deflections of the drilled shafts increased much faster than the predictons due to crack propagation in the concrete. The predictions for the steel pipe pile were good throughout the entire loading range. The predictions were too stiff for the prestressed concrete pile at larger loads using both the prebored PMT and the driven CPMT test curves, with the prebored data yielding the best results of the two. From these results it can be concluded that the pressuremeter method predicts well the soil response but does not include any pile stiffness degradation.

- The conventional P-y curves overpredicted the displacement of the piles throughout the entire loading range.

- For all piles the predicted increase in deflection due to cyclic loading was much less than the measured increase. Four possible reasons for this difference are: (1) the difference in confinement between the pile and the pressuremeter, (2) load-control cyclic pile load tests may not cause exclusively load-control cyclic loading of each soil strata, (3) influence of previous series of cycles on subsequent series of cycles during a test and (4) degradation of the pile flexural stiffness during cyclic loading.

- The average cyclic degradation parameter from the pressuremeter tests (a = 0.064) matches very well the average cyclic degradation parameter from the pile load tests which should experience little or no degradation of the pile flexural stiffness, namely the steel pipe pile (a = 0.062) and the prestressed concrete pile (a = 0.063). The reinforced concrete drilled shafts showed much higher cyclic degradation.

- The creep exponents from the PMT tests were 0.006 for the prebored TEXAM tests and 0.011 for the driven CPMT tests. These exponents were lower than the creep exponents backcalculated from the pile load tests which stabilized around 0.015 to 0.02. The difference may be caused by two of the mechanisms cited for the underprediction of cyclic degradation, namely the difference in confinement between the pile and the pressuremeter probe and the creep of the pile flexural stiffness under a sustained load.

The following recommendations are made based on the results of this study:

- The pressuremeter method used in this study for predicting pile response to monotonic lateral loading (Little and Briaud, 1987) is applicable to piles which will experience little or no degradation in

flexural stiffness (such as steel piles, prestressed concrete piles loaded less than the prestress, etc.) due to the applied loading.

- Further study needs to be done in four main areas in order to apply the pressuremeter method to cyclic and creep loading. These areas are (1) the effects of the difference in confinement between the pile and the pressuremeter probe, (2) determining what type of loading each soil strata actually undergoes due to various loading at the top of the pile, (3) the influence of previous series of cycles on subsequent series of cycles and (4) the degradation of the pile flexural stiffness during loading (monotonic, cyclic and creep).

  The fourth item relating to degradation of the pile flexural stiffness during loading is felt to be the most critical factor for prediction of the behavior of reinforced concrete drilled shafts.

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MAKARIM, C.A. AND BRIAUD, J.-L., 1986, "Pressuremeter Method for Single Piles Subjected to Cyclic Lateral Loads in Overconsolidated Clay," Research Report No. 5112, Civil Engineering Department, Texas A&M University, College Station, Texas.

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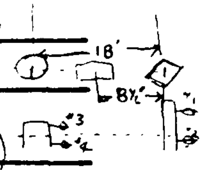
# APPENDIX A

# PILE LOAD TEST DATA

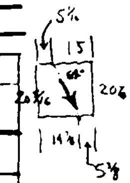
TUNNEL SITE
PILE LOAD TEST DATA

Test Pile: 20 inch SQUARE CONCRETE  Date: 1-6-87

Reaction Pile: 42 inch DRILLED SHAFT




Displacement gage locations:
- #1: 3/8" TO RIGHT OF LOAD AXIS & 21 1/16 ABOVE (ON BACK SIDE
- #2: 1/4" TO RIGHT OF LOAD AXIS & 8 5/16" BELOW OF PILE)
- #3: 1 3/4" TO RIGHT OF LOAD AXIS & 8½" ABOVE (ON INSIDE
- #4: 2 7/8" TO RIGHT OF LOAD AXIS & 9 3/8" BELOW OF PILE)




| | Time min: sec | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (in) | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (in) |
|---|---|---|---|---|---|---|---|
| 13:23 | 0 | 410 | 560 | 7.800 | 6.428 | 0.143 | 0.026 |
| | 30s | 5000 | 800 | 7.794 | 6.411 | 0.148 | 0.028 |
| At 1:20 Jack for[illegible] and [illegible] the 6 [illegible] over ~ 20 s | 1:30 | 4950 | 800 | 7.794 | 6.411 | 0.148 | 0.028 |
| | 2:30 | 5050 | 800 | 7.794 | 6.410 | 0.148 | 0.029 |
| | 3:30 | 5000 | 800 | 7.794 | 6.410 | 0.148 | 0.029 |
| | 4:30 | 5000 | 800 | 7.794 | 6.410 | 0.148 | 0.029 |
| | 5:30 | 10000 | 1080 | 7.759 | 6.384 | 0.154 | 0.032 |
| | 6:30 | 10000 | 1080 | 7.756 | 6.383 | 0.154 | 0.032 |
| | 7:30 | 10000 | 1080 | 7.755 | 6.383 | 0.154 | 0.032 |
| | 8:30 | " | " | 7.755 | 6.383 | 0.154 | 0.032 |
| | 9:30 | " | " | 7.754 | 6.383 | 0.154 | 0.032 |
| load starts going ↓ immediately after this rdg and takes ~ 20 s. to go to next load. | 10:30 | " | " | 7.754 | 6.381 | 0.154 | 0.032 |
| | 11:30 | 15050 | 1360 | 7.707 | 6.350 | 0.162 | 0.039 |
| | 12:30 | 15000 | " | 7.704 | 6.348 | 0.162 | 0.039 |
| | 13:30 | " | " | 7.703 | 6.348 | 0.163 | 0.040 |
| | 14:30 | " | " | 7.703 | 6.347 | 0.164 | 0.041 |
| | 15:30 | " | " | 7.703 | 6.347 | 0.164 | 0.041 |
| | 16:30 | " | " | 7.702 | 6.347 | 0.165 | 0.042 |
| | 17:30 | 20000 | 1500 | 7.648 | 6.314 | 0.173 | 0.049 |
| | 18:30 | " | " | 7.643 | 6.313 | 0.174 | 0.050 |
| | 19:30 | " | " | 7.641 | 6.312 | 0.176 | 0.053 |
| | 20:30 | " | " | 7.640 | 6.312 | 0.176 | 0.053 |
| | 21:30 | " | " | 7.639 | 6.311 | 0.177 | 0.054 |
| hairline crack-gap behind | 22:30 | " | " | 7.639 | 6.311 | 0.177 | 0.054 |
| | 23:30 | 25000 | 1700 | 7.581 | 6.272 | [illegible] | 0.061 |
| | 24:30 | " | " | 7.576 | 6.269 | 0.187 | 0.063 |
| | 25:30 | " | " | 7.574 | 6.267 | [illegible] | 0.064 |
| | 26:30 | " | " | 7.572 | 6.266 | [illegible] | 0.065 |
| | 27:30 | " | " | 7.571 | 6.265 | 0.189 | 0.066 |
| | 28:30 | " | " | 7.569 | 6.265 | 0.189 | [illegible] |
| | 29:30 | 30000 | 1920 | 7.512 | 6.222 | 0.199 | 0.076 |
| | 30:30 | " | " | 7.506 | 6.219 | 0.200 | 0.078 |
| square pile twist slightly 1/8" hor. | 31:30 | " | " | 7.503 | 6.216 | 0.201 | 0.078 |
| | 32:30 | " | " | 7.500 | 6.215 | 0.202 | 0.079 |
| | 33:30 | " | " | [illegible] | 6.214 | [illegible] | 0.079 |
| | 34:30 | " | " | 7.498 | 6.213 | [illegible] | 0.080 |

TUNNEL SITE
PILE LOAD TEST DATA

Continuation of: Date: Jan 6, 87.

| | Time (min:sec.) | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (in) | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (in) |
|---|---|---|---|---|---|---|---|
| first | 36:30 | 650 | 600 | 7.725 | 6.373 | 0.166 | 0.054 |
| | 38:30 | 30000 | 1900 | 7.482 | 6.202 | 0.205 | 0.083 |
| | 40:30 | 650 | 600 | 7.720 | 6.364 | 0.168 | 0.054 |
| | 42:30 | 30000 | 1900 | 7.471 | 6.194 | 0.208 | 0.086 |
| | 44:30 | 550 | 600 | 7.708 | 6.360 | 0.173 | 0.061 |
| | 46:30 | 30000 | 1920 | 7.464 | 6.187 | 0.212 | 0.091 |
| | 48:30 | 600 | 600 | 7.706 | 6.354 | 0.175 | 0.063 |
| 2nd | 50:30 | 30000 | 1920 | 7.460 | 6.183 | 0.214 | 0.092 |
| | 52:30 | 600 | 600 | 7.699 | 6.348 | 0.177 | 0.064 |
| | 54:30 | 30000 | 1920 | 7.455 | 6.175 | 0.216 | 0.094 |
| | 56:30 | 550 | 600 | 7.694 | 6.345 | 0.178 | 0.066 |
| | 58:30 | 30000 | 1920 | 7.456 | 6.273 | 0.218 | 0.096 |
| | 60:30 | 550 | 600 | 7.690 | 6.343 | 0.180 | 0.068 |
| | 62:30 | 30000 | 1900 | 7.450 | 6.170 | 0.220 | 0.097 |
| Soil Crack in back of reaction shaft → | 64:30 | 550 | 600 | 7.697 | 6.336 | 0.183 | 0.073 |
| | 66:30 | 30000 | 1920 | 7.455 | 6.165 | 0.224 | 0.104 |
| | 68:30 | 600 | 600 | 7.696 | 6.335 | 0.186 | 0.078 |
| | 70:30 | 30050 | 1920 | 7.453 | 6.165 | 0.226 | 0.106 |
| | 72:30 | 600 | 600 | 7.696 | 6.333 | 0.186 | 0.080 |
| | 74:30 | 30000 | 1920 | 7.450 | 6.166 | 0.217 | 0.109 |
| | 76:30 | 14850 | 1200 | 7.545 | 6.231 | 0.210 | 0.099 |
| | 78:30 | 30000 | 1920 | 7.447 | 6.164 | 0.230 | 0.113 |
| | 80:30 | 14950 | 1150 | 7.538 | 6.229 | 0.212 | 0.104 |
| | 82:30 | 30000 | 1900 | 7.444 | 6.161 | 0.231 | 0.118 |
| | 84:30 | 14850 | 1100 | 7.538 | 6.225 | [illegible] | 0.104 |
| | 86:30 | 30000 | 1920 | 7.441 | 6.159 | 0.231 | 0.118 |
| | 88:30 | 14950 | 1150 | 7.536 | 6.221 | 0.212 | 0.104 |
| | 90:30 | 30000 | 1900 | 7.440 | 6.157 | 0.232 | 0.119 |
| | 92:30 | 14900 | 1120 | 7.533 | 6.221 | 0.214 | 0.105 |
| | 94:30 | 30000 | 1900 | 7.437 | 6.155 | 0.231 | 0.119 |
| | 96:30 | 15000 | 1120 | 7.528 | 6.217 | 0.214 | 0.104 |
| 15:02 | 98:30 | 30000 | 1900 | 7.436 | 6.152 | 0.232 | 0.119 |
| | 100:30 | 15000 | 1150 | 7.528 | 6.217 | 0.215 | 0.106 |
| | 102:30 | 30000 | 1900 | 7.435 | 6.154 | 0.234 | 0.121 |
| | 104:30 | 14950 | 1150 | 7.527 | 6.217 | 0.216 | 0.109 |
| | 106:30 | 30000 | 1900 | 7.434 | 6.153 | 0.234 | 0.120 |
| bottom 19 | 108:30 | 14950 | 1150 | 7.527 | 6.217 | 0.216 | 0.109 |
| top 20 | 110:30 | 30000 | 1900 | 7.433 | 6.153 | 0.234 | 0.123 |
| bottom 20 top 21 | 112:30 | 15000 | 1150 | 7.525 | 6.216 | 0.218 | 0.110 |
| | 114:30 | 30000 | 1900 | 7.433 | 6.153 | 0.236 | 0.124 |
| | 115:30 | 35000 | 2120 | 7.389 | 6.125 | 0.245 | 0.130 |
| | 116:30 | 〃 | 〃 | 7.385 | 6.122 | 0.247 | 0.133 |

TUNNEL SITE
PILE LOAD TEST DATA

0.715 → 0.275
0.558 →
0.054 → 0.048
0.153 →

Continuation of: Date:

| Time min:sec | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (6.328) (in) | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (0.075) (in) |
|---|---|---|---|---|---|---|
| 117:30 | 35000 | 2120 | 7.382 | 6.121 | 0.248 | 0.133 |
| 118:30 | " | " | 7.380 | 6.120 | 0.248 | 0.134 |
| 119:30 | " | 2150 | 7.379 | 6.119 | 0.248 | 0.134 |
| 120:30 | " | " | 7.377 | 6.117 | 0.249 | 0.134 |
| 121:30 | 40000 | 2500 | 7.317 | 6.076 | 0.260 | 0.142 |
| 122:30 | " | " | 7.308 | 6.071 | 0.262 | 0.144 |
| 123:30 | " | " | 7.304 | 6.069 | 0.263 | 0.144 |
| 124:30 | " | 2480 | 7.301 | 6.066 | 0.264 | 0.145 |
| 125:30 | " | " | 7.299 | 6.065 | 0.264 | 0.145 |
| 126:30 | " | " | 7.299 | 6.064 | 0.264 | 0.145 |
| 127:30 | 45000 | 2700 | 7.233 | 6.010 | 0.278 | 0.156 |
| 128:30 | " | 2680 | 7.221 | 6.003 | 0.281 | 0.160 |
| 129:30 | " | " | 7.213 | 5.997 | 0.281 | 0.163 |
| 130:30 | " | " | 7.208 | 5.994 | 0.282 | 0.164 |
| 131:30 | " | " | 7.205 | 5.991 | 0.282 | 0.164 |
| 132:30 | " | " | 7.202 | 5.989 | 0.283 | 0.164 |
| 133:30 | 50000 | 2850 | 7.111 | 5.919 | 0.298 | 0.175 |
| 134:30 | " | " | 7.099 | 5.909 | 0.302 | 0.178 |
| 135:30 | " | " | 7.087 | 5.901 | 0.304 | 0.180 |
| 136:30 | " | 2840 | 7.081 | 5.896 | 0.305 | 0.181 |
| 137:30 | " | " | 7.075 | 5.893 | 0.306 | 0.181 |
| top 1 138:30 | " | " | 7.071 | 5.890 | 0.307 | 0.182 |
| bottom 1 140:30 | 25150 | 1580 | 7.285 | 6.022 | 0.266 | 0.155 |
| top 2 142:30 | 50000 | 2820 | 7.046 | 5.860 | 0.309 | 0.187 |
| 144:30 | 25100 | 1580 | 7.265 | 6.001 | 0.268 | 0.160 |
| 146:30 | 50000 | 2800 | 7.019 | 5.836 | 0.311 | 0.190 |
| 148:30 | 25050 | 1560 | 7.246 | 5.984 | 0.270 | 0.161 |
| 150:30 | 50000 | 2800 | 6.989 | 5.821 | 0.312 | 0.192 |
| 152:30 | 24900 | 1580 | 7.222 | 5.964 | 0.273 | 0.164 |
| 1/4 in gap behind sq. pile 154:30 | 50000 | 2800 | 6.964 | 5.804 | 0.314 | 0.195 |
| 156:30 | 25100 | 1580 | 7.212 | 5.954 | 0.272 | 0.164 |
| 158:30 | 50000 | 2800 | 6.952 | 5.790 | 0.315 | 0.195 |
| 160:30 | 25150 | 1580 | 7.199 | 5.943 | 0.273 | 0.165 |
| 162:30 | 50000 | 2800 | 6.935 | 5.778 | 0.316 | 0.197 |
| 164:30 | 25100 | 1600 | 7.184 | 5.936 | 0.273 | 0.166 |
| 166:30 | 50000 | 2800 | 6.916 | 5.768 | 0.316 | 0.198 |
| 168:30 | 25050 | 1580 | 7.173 | 5.925 | 0.274 | 0.166 |
| 170:30 | 50000 | 2800 | 6.904 | 5.757 | 0.317 | 0.198 |
| 172:30 | 25100 | 1580 | 7.159 | 5.916 | 0.275 | 0.167 |
| 174:30 | 50000 | 2800 | 6.893 | 5.748 | 0.316 | 0.200 |
| 176:30 | 25050 | 1600 | 7.173 | 5.921 | 0.272 | 0.165 |
| 178:30 | 50000 | 2800 | 6.880 | 5.742 | 0.318 | 0.199 |

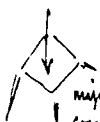
TUNNEL SITE
PILE LOAD TEST DATA

Continuation of: Date:

| | Time | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 ~~7.501~~ (in) | Test Pile Disp. #2 ~~6.0??~~ (in) | Reaction Pile Disp. #3 ~~0.[illegible]~~ (in) | Reaction Pile Disp. #4 (0.016) (in) |
|---|---|---|---|---|---|---|---|
| | min:sec | | | | | | |
| bottom 11 | 180:30 | 950 | 580 | 7.505 | 6.157 | 0.217 | 0.118 |
| | 182:30 | 50000 | 2800 | 6.891 | 5.740 | 0.317 | 0.199 |
| | 184:30 | 950 | 580 | 7.500 | 6.153 | 0.217 | 0.119 |
| | 186:30 | 50000 | 2800 | 6.877 | 5.729 | 0.320 | 0.200 |
| | 188:30 | 1000 | 580 | 7.494 | 6.145 | 0.217 | 0.119 |
| | 190:30 | 50000 | 2800 | 6.858 | 5.718 | 0.322 | 0.201 |
| | 192:30 | 850 | 580 | 7.490 | 6.133 | 0.218 | 0.121 |
| | 194:30 | 50000 | 2800 | 6.842 | 5.805 | 0.325 | 0.204 |
| | 196:30 | 1100 | 580 | 7.472 | 6.122 | 0.220 | 0.132 |
| Sand fill behind sq pile to close gap. | 198:30 | 50000 | 2800 | 6.827 | 5.694 | 0.326 | 0.205 |
| | 200:30 | 1250 | 600 | 7.459 | 6.109 | 0.221 | 0.124 |
| | 202:30 | 50000 | 2800 | 6.816 | 5.683 | 0.328 | 0.207 |
| | 204:30 | 1050 | 600 | 7.455 | 6.107 | 0.220 | 0.124 |
| | 206:30 | 50000 | 2800 | 6.805 | 5.675 | 0.328 | 0.209 |
| | 208:30 | 1000 | 600 | 7.447 | 6.100 | 0.220 | 0.123 |
| | 210:30 | 50000 | 2800 | 6.797 | 5.670 | 0.327 | 0.210 |
| | 212:30 | 850 | 600 | 7.439 | 6.092 | 0.221 | 0.124 |
| | 214:30 | 50000 | 2800 | 6.782 | 5.658 | 0.331 | 0.210 |
| bottom 20 | 216:30 | 900 | 600 | 7.424 | 6.079 | 0.222 | 0.125 |
| | 218:30 | 50000 | 2800 | 6.770 | 5.650 | 0.332 | 0.210 |
| | 219:30 | 55000 | 3040 | 6.680 | 5.575 | 0.350 | 0.223 |
| | 220:30 | " | " | 6.667 | 5.567 | 0.352 | 0.226 |
| | 221:30 | - No Rdg - | — | — | — | — | — |
| | 222:30 | 55000 | 3050 | 6.654 | 5.560 | 0.355 | 0.229 |
| | 223:30 | " | 3050 | 6.650 | 5.556 | 0.355 | 0.230 |
| | 224:30 | " | " | 6.646 | 5.553 | 0.356 | 0.230 |
| | 225:30 | 60000 | 3240 | 6.535 | 5.475 | 0.372 | 0.241 |
| | 226:30 | " | 3250 | 6.515 | 5.457 | 0.376 | 0.244 |
| | 227:30 | " | " | 6.504 | 5.449 | 0.378 | 0.245 |
| | 228:30 | " | " | 6.497 | 5.444 | 0.380 | 0.247 |
| | 229:30 | " | " | 6.492 | 5.440 | 0.381 | 0.247 |
| | 230:30 | " | 3240 | 6.485 | 5.437 | 0.381 | 0.247 |
| | 231:30 | 65000 | 3400 | 6.343 | 5.327 | 0.399 | 0.263 |
| | 232:30 | " | " | 6.319 | 5.308 | 0.404 | 0.266 |
| | 233:30 | " | " | 6.304 | 5.297 | 0.406 | 0.268 |
| | 234:30 | " | " | 6.290 | 5.286 | 0.408 | 0.271 |
| | 235:30 | " | " | 6.285 | 5.281 | 0.409 | 0.271 |
| | 236:30 | " | " | 6.277 | 5.277 | 0.410 | 0.271 |
| | 237:30 | 70000 | 3680 | 6.090 | 5.130 | 0.432 | 0.286 |
| | 238:30 | " | " | 6.060 | 5.109 | 0.436 | 0.290 |
| | 239:30 | " | 3660 | 6.037 | 5.096 | 0.440 | 0.292 |
| | 240:30 | " | " | 6.027 | 5.086 | 0.442 | 0.294 |

TUNNEL SITE
PILE LOAD TEST DATA

Continuation of: Date:



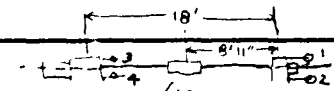
major cracks sq. pile (1/4 in wide, 1 ft long)

| Time min:sec | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (6.420) (in) | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (in) |
|---|---|---|---|---|---|---|
| 241:30 | 70000 | 3660 | 6.013 | 5.077 | 0.443 | 0.295 |
| 242:30 | " | " | 6.003 | 5.071 | 0.445 | 0.295 |
| 243:30 | 75000 | 3840 | 5.772 | 4.911 | 0.466 | 0.311 |
| 244:30 | " | 3820 | 5.727 | 4.883 | 0.473 | 0.315 |
| 245:30 | " | " | 5.705 | 4.863 | 0.476 | 0.318 |
| 246:30 | " | " | 5.687 | 4.845 | 0.479 | 0.320 |
| 247:30 | " | " | 5.672 | 4.834 | 0.480 | 0.324 |
| 248:30 | " | " | 5.658 | 4.825 | 0.481 | 0.325 |
| 249:30 | 80000 | 4080 | 5.406 | 4.622 | 0.502 | 0.341 |
| 250:30 | " | 4100 | 5.331 | 4.576 | 0.511 | 0.346 |
| 251:30 | " | " | 5.302 | 4.551 | 0.515 | 0.349 |
| 252:30 | " | " | 5.276 | 4.532 | 0.517 | 0.351 |
| 253:30 | " | " | 5.242 | 4.570 | 0.520 | 0.353 |
| 254:30 | " | " | 5.232 | 4.503 | 0.522 | 0.355 |
| 255:30 | 85000 | 4380 | 4.891 | 4.266 | 0.545 | 0.371 |
| 256:30 | " | 4400 | 4.803 | 4.206 | 0.553 | 0.376 |
| 257:30 | " | " | 4.757 | 4.170 | 0.558 | 0.380 |
| 258:30 | " | " | 4.721 | 4.141 | 0.561 | 0.382 |
| 259:30 | " | " | 4.696 | 4.124 | 0.564 | 0.384 |
| 260:30 | " | " | 4.669 | 4.107 | 0.566 | 0.386 |
| 261:30 | 90000 | 4600 | 4.195 | 3.840 | 0.591 | 0.405 |
| 262:30 | " | 4650 | 4.015 | 3.630 | 0.598 | 0.411 |
| 263:30 | " | 4680 | 3.850 | 3.520 | 0.603 | 0.415 |
| 264:30 | " | 4720 | 3.655 | 3.380 | 0.633 x | 0.450 x |
| 265:30 | " | " | 3.418 | 3.200 | 0.753 | 0.550 |
| 266:30 | " | " | 3.040 | 2.960 | >1.000 | 0.740 ? |
| | | | | | | |
| | | | | | | |
| — | 00000 | Reading at | "No LOAD" | CONDITION | AFTER TEST | — |

TUNNEL SITE
PILE LOAD TEST DATA

Test Pile: 24" DIA. OPEN ENDED PIPE PILE    Date: 1-7-87

Reaction Pile: 42" DIA DRILLED SHAFT




Displacement gage locations:
#1: 11 9/16" ABOVE LOAD AXIS, 1/4" TO THE RIGHT (AS FACING OUTSIDE OF PILE)
#2: 4 15/16" BELOW LOAD AXIS, 3/8" TO THE RIGHT
#3: 11 7/8" ABOVE LOAD AXIS, 7/16" TO THE LEFT (AS FACING INSIDE OF PILE)
#4: 4 9/16" BELOW LOAD AXIS, 1/16" TO THE LEFT

| | Time | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (in) | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (in) |
|---|---|---|---|---|---|---|---|
| | min:sec | | | | | | |
| | — | 00000 | "NO LOAD" READING | BEFORE TEST SET UP | | | |
| 11:50 | 0 | 0 | 500 | +5.548 | +6.521 | -0.008 | +0.036 |
| | 30 sec | 5150 | 800 | 5.529 | 6.520 | -0.002 | 0.040 |
| | 1:30 | 5000 | 800 | 5.528 | 6.520 | -0.002 | 0.040 |
| | 2:30 | " | " | 5.528 | 6.520 | -0.002 | 0.040 |
| | 3:30 | " | " | 5.528 | 6.520 | -0.002 | 0.040 |
| | 4:30 | " | 780 | 5.528 | 6.520 | -0.002 | 0.040 |
| | 5:30 | 10000 | 1000 | 5.501 | 6.502 | 0.006 | 0.045 |
| | 6:30 | " | " | 5.500 | 6.502 | 0.006 | 0.046 |
| | 7:30 | " | " | 5.500 | 6.501 | 0.006 | 0.046 |
| | 8:30 | " | " | 5.499 | 6.501 | 0.006 | 0.046 |
| | 9:30 | " | " | 5.499 | 6.500 | 0.006 | 0.046 |
| | 10:30 | " | " | 5.499 | 6.500 | 0.007 | 0.046 |
| | 11:30 | 15000 | 1320 | 5.468 | 6.478 | 0.015 | 0.052 |
| | 12:30 | " | " | 5.466 | 6.477 | 0.015 | 0.053 |
| | 13:30 | " | " | 5.465 | 6.477 | 0.016 | 0.053 |
| | 14:30 | " | " | 5.465 | 6.476 | 0.016 | 0.053 |
| | 15:30 | " | " | 5.464 | 6.476 | 0.016 | 0.053 |
| | 16:30 | " | " | 5.464 | 6.476 | 0.016 | 0.053 |
| | 17:30 | 20000 | 1420 | 5.429 | 6.449 | 0.026 | 0.061 |
| | 18:30 | " | " | 5.427 | 6.447 | 0.027 | 0.061 |
| | 19:30 | " | " | 5.426 | 6.446 | 0.027 | 0.061 |
| | 20:30 | " | " | 5.425 | 6.446 | 0.027 | 0.061 |
| | 21:30 | " | " | 5.424 | 6.446 | 0.027 | 0.062 |
| | 22:30 | " | " | 5.424 | 6.446 | 0.028 | 0.062 |
| | 23:30 | 25000 | 1680 | 5.384 | 6.415 | 0.039 | 0.070 |
| | 24:30 | " | " | 5.380 | 6.412 | 0.040 | 0.071 |
| | 25:30 | " | " | 5.378 | 6.411 | 0.041 | 0.072 |
| | 26:30 | " | " | 5.377 | 6.410 | 0.041 | 0.072 |
| | 27:30 | " | " | 5.376 | 6.409 | 0.042 | 0.073 |
| | 28:30 | " | " | 5.375 | 6.408 | 0.042 | 0.073 |
| | 29:30 | 30000 | 1900 | 5.331 | 6.374 | 0.055 | 0.084 |
| | 30:30 | " | " | 5.327 | 6.374 | 0.057 | 0.085 |
| | 31:30 | " | " | 5.324 | 6.372 | 0.058 | 0.085 |
| | 32:30 | " | " | 5.323 | 6.371 | [illegible] | 0.085 |
| | 33:30 | " | 1910 | 5.322 | 6.370 | 0.058 | 0.086 |

0.294 → 0.311
0.084 → 0.[illegible]

# TUNNEL SITE
## PILE LOAD TEST DATA

Continuation of: Pipe pile    Date: 1-7-87

| | Time (min:sec) | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (6.531) (in) | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (0.036) (in) |
|---|---|---|---|---|---|---|---|
| | 34:30 | 30000 | 1920 | 5.321 | 6.370 | 0.059 | 0.086 |
| 1/8" gap behind pipe pile | 35:30 | 35000 | 2200 | 5.274 | 6.334 | 0.072 | 0.098 |
| | 36:30 | " | " | 5.270 | 6.330 | 0.075 | 0.099 |
| | 37:30 | " | " | 5.267 | 6.327 | 0.076 | 0.101 |
| | 38:30 | " | " | 5.265 | 6.325 | 0.077 | 0.101 |
| | 39:30 | " | " | 5.264 | 6.324 | 0.078 | 0.101 |
| | 40:30 | " | " | 5.262 | 6.322 | 0.078 | 0.102 |
| | 41:30 | 40000 | 2420 | 5.215 | 6.285 | 0.093 | 0.115 |
| | 42:30 | " | " | 5.209 | 6.280 | 0.096 | 0.117 |
| | 43:30 | " | " | 5.205 | 6.278 | 0.097 | 0.119 |
| | 44:30 | " | " | 5.203 | 6.276 | 0.098 | 0.120 |
| | 45:30 | " | " | 5.201 | 6.274 | 0.099 | 0.120 |
| | 46:30 | " | " | 5.198 | 6.272 | 0.100 | 0.120 |
| bottom of 1 | 48:30 | 650 | 520 | 5.466 | 6.464 | 0.017 | 0.078 |
| | 50:30 | 40000 | 2420 | 5.180 | 6.256 | 0.100 | 0.135 |
| 2 | 52:30 | 650 | 520 | 5.455 | 6.455 | 0.020 | 0.084 |
| | 54:30 | 40000 | 2420 | 5.165 | 6.245 | 0.103 | 0.142 |
| 3 | 56:30 | 650 | 520 | 5.448 | 6.449 | 0.022 | 0.083 |
| | 58:30 | 40000 | 2420 | 5.153 | 6.232 | 0.106 | 0.145 |
| 4 | 60:30 | 550 | 520 | 5.444 | 6.444 | 0.025 | 0.085 |
| | 62:30 | 40000 | 2420 | 5.146 | 6.226 | 0.109 | 0.146 |
| 5 | 64:30 | 550 | 520 | 5.440 | 6.440 | 0.026 | 0.086 |
| | 66:30 | 40000 | 2420 | 5.140 | 6.221 | 0.111 | 0.148 |
| 6 | 68:30 | 600 | 520 | 5.437 | 6.438 | 0.028 | 0.088 |
| | 70:30 | 40000 | 2420 | 5.136 | 6.219 | 0.113 | 0.150 |
| 7 | 72:30 | 650 | 540 | 5.433 | 6.434 | 0.030 | 0.089 |
| | 74:30 | 40000 | 2420 | 5.130 | 6.215 | 0.115 | 0.152 |
| 8 | 76:30 | 650 | 520 | 5.430 | 6.432 | 0.031 | 0.091 |
| | 78:30 | 40000 | 2420 | 5.127 | 6.211 | 0.117 | 0.154 |
| 9 | 80:30 | 600 | 520 | 5.428 | 6.431 | 0.032 | 0.091 |
| | 82:30 | 40000 | 2420 | 5.123 | 6.210 | 0.119 | 0.155 |
| 10 | 84:30 | 600 | 540 | 5.425 | 6.428 | 0.033 | 0.092 |
| | 86:30 | 40000 | 2450 | 5.122 | 6.207 | 0.119 | 0.155 |
| 11 | 88:30 | 20000 | 1350 | 5.229 | 6.278 | 0.082 | 0.130 |
| | 90:30 | 40000 | 2480 | 5.113 | 6.201 | 0.123 | 0.159 |
| 12 | 92:30 | 20100 | 1340 | 5.221 | 6.271 | 0.085 | 0.133 |
| | 94:30 | 40000 | 2480 | 5.110 | 6.197 | 0.124 | 0.160 |
| 13 | 96:30 | 20050 | 1350 | 5.217 | 6.267 | 0.086 | 0.134 |
| | 98:30 | 40000 | 2450 | 5.107 | 6.195 | 0.126 | [illegible] |
| 14 | 100:30 | 20000 | 1350 | 5.214 | 6.265 | 0.088 | 0.135 |
| | 102:30 | 40000 | 2450 | 5.103 | 6.192 | 0.127 | 0.162 |
| 15 | 104:30 | 20050 | 1350 | 5.211 | 6.262 | 0.089 | 0.136 |

~~0.249~~ 0.501
~~0.004~~ 0.226

# TUNNEL SITE
## PILE LOAD TEST DATA

Continuation of: Pipe Pile                                        Date: 1-7-87

| | Time | Load Cell Reading | Pressure in Jack | Test Pile Disp. | | Reaction Pile Disp. | |
|---|---|---|---|---|---|---|---|
| | min:sec | (lbs.) | (psi) | #1 (in) (5.548) | #2 (in) (6.521) | #3 (in) | #4 (in) ~~(0.036)~~ |
| | 106:30 | 40000 | 2460 | 5.102 | 6.191 | 0.128 | 0.163 |
| 16 | 108:30 | 20050 | 1350 | 5.210 | 6.262 | 0.090 | 0.137 |
| | 110:30 | 40000 | 2450 | 5.100 | 6.189 | 0.129 | 0.164 |
| 17 | 112:30 | 20050 | 1340 | 5.207 | 6.260 | 0.092 | 0.139 |
| | 114:30 | 40000 | 2450 | 5.098 | 6.188 | 0.131 | 0.165 |
| 18 | 116:30 | 20050 | 1350 | 5.206 | 6.259 | 0.093 | 0.140 |
| | 118:30 | 40000 | 2450 | 5.097 | 6.188 | 0.132 | 0.166 |
| 19 | 120:30 | 20000 | 1340 | 5.205 | 6.258 | 0.094 | 0.140 |
| | 122:30 | 40000 | 2450 | 5.096 | 6.187 | 0.132 | 0.167 |
| 20 | 124:30 | 20000 | 1320 | 5.205 | 6.259 | 0.094 | 0.141 |
| | 126:30 | 40000 | 2460 | 5.095 | 6.187 | 0.133 | 0.167 |
| | 127:30 | 45000 | 2660 | 5.063 | 6.163 | 0.147 | 0.179 |
| | 128:30 | " | 2650 | 5.060 | 6.160 | 0.149 | 0.181 |
| | 129:30 | " | 2640 | 5.058 | 6.159 | 0.150 | 0.181 |
| | 130:30 | " | 2650 | 5.057 | 6.158 | 0.151 | 0.182 |
| | 131:30 | " | 2650 | 5.056 | 6.157 | 0.152 | 0.183 |
| | 132:30 | " | " | 5.055 | 6.157 | 0.153 | 0.184 |
| | 133:30 | 50000 | 2820 | 5.023 | 6.124 | 0.169 | 0.197 |
| | 134:30 | " | 2840 | 5.017 | 6.120 | 0.174 | 0.200 |
| | 135:30 | " | 2820 | 5.014 | 6.117 | 0.176 | 0.201 |
| | 136:30 | " | " | 5.013 | 6.116 | 0.177 | 0.202 |
| | 137:30 | " | " | 5.011 | 6.115 | 0.178 | 0.204 |
| | 138:30 | " | " | 5.010 | 6.114 | 0.179 | 0.205 |
| | 139:30 | 55000 | 3020 | 4.968 | 6.081 | 0.199 | 0.222 |
| | 140:30 | " | 3000 | 4.962 | 6.077 | 0.204 | 0.225 |
| | 141:30 | " | " | 4.959 | 6.074 | 0.206 | 0.227 |
| | 142:30 | " | " | 4.956 | 6.072 | 0.208 | 0.228 |
| | 143:30 | " | " | 4.954 | 6.070 | 0.210 | 0.230 |
| | 144:30 | " | " | 4.953 | 6.069 | 0.211 | 0.231 |
| | 145:30 | 60000 | 3300 | 4.908 | 6.034 | 0.235 | 0.251 |
| | 146:30 | " | " | 4.900 | 6.030 | 0.240 | 0.255 |
| | 147:30 | " | " | 4.897 | 6.025 | 0.243 | 0.258 |
| | 148:30 | " | " | 4.893 | 6.022 | 0.245 | 0.260 |
| | 149:30 | " | " | 4.890 | 6.020 | 0.247 | 0.261 |
| | 150:30 | " | " | 4.858 | 6.020 | 0.249 | 0.262 |
| bottom 1 | 152:30 | 30100 | 1700 | 5.027 | 6.120 | 0.174 | 0.215 |
| | 154:30 | 60000 | 3320 | 4.870 | 6.004 | 0.255 | 0.274 |
| 2 | 156:30 | 30050 | 1700 | 5.022 | 6.106 | 0.182 | 0.222 |
| | 158:30 | 60000 | 3360 | 4.860 | 5.990 | 0.260 | 0.278 |
| 3 | 160:30 | 30100 | 1700 | 5.018 | 6.097 | 0.184 | 0.225 |
| | 162:30 | 60000 | 3360 | 4.846 | 5.978 | 0.267 | 0.286 |
| 4 | 164:30 | 30050 | [illegible] | 5.006 | 6.088 | [illegible] | 0.230 |

0.501
0.226

TUNNEL SITE
PILE LOAD TEST DATA

Continuation of: Date: 1-7-87

| | Time | Load Cell Reading (lbs.) | Pressure in Jack | Test Pile Disp. | | Reaction Pile Disp. | |
|---|---|---|---|---|---|---|---|
| | min:sec | | (psi) | #1 (in) | #2 (in) (6.5 FT) | #3 (in) | #4 (in) (2.036) |
| | 166:30 | 60000 | 3360 | 4.836 | 5.970 | 0.273 | 0.291 |
| 5 | 168:30 | 30050 | 1700 | 4.997 | 6.081 | 0.195 | 0.235 |
| | 170:30 | 60000 | 3380 | 4.829 | 5.964 | 0.276 | 0.294 |
| 6 | 172:30 | 30150 | 1750 | 4.991 | 6.076 | 0.198 | 0.238 |
| | 174:30 | 60000 | 3380 | 4.822 | 5.959 | 0.280 | 0.297 |
| 7 | 176:30 | 30000 | 1700 | 4.986 | 6.071 | 0.202 | 0.241 |
| | 178:30 | 60000 | 3360 | 4.816 | 5.954 | 0.284 | 0.300 |
| 8 | 180:30 | 30000 | 1700 | 4.980 | 6.067 | 0.205 | 0.244 |
| | 182:30 | 60000 | 3400 | 4.809 | 5.948 | 0.287 | 0.303 |
| 9 | 184:30 | 30000 | 1700 | 4.975 | 6.062 | 0.208 | 0.247 |
| | 186:30 | 60000 | 3400 | 4.804 | 5.944 | 0.290 | 0.306 |
| 10 | 188:30 | 30050 | 1720 | 4.969 | 6.057 | 0.211 | 0.250 |
| | 190:30 | 60000 | 3400 | 4.799 | 5.940 | 0.292 | 0.309 |
| 11 | 192:30 | 850 | 540 | 5.340 | 6.350 | 0.108 | 0.162 |
| | 194:30 | 60000 | 3360 | 4.804 | 5.939 | 0.293 | 0.308 |
| 12 | 196:30 | 950 | 540 | 5.337 | 6.342 | 0.107 | 0.162 |
| | 198:30 | 60000 | 3380 | 4.797 | 5.933 | 0.297 | 0.312 |
| 13 | 200:30 | 700 | 540 | 5.338 | 6.342 | 0.107 | 0.164 |
| | 202:30 | 60000 | 3380 | 4.787 | 5.926 | 0.302 | 0.317 |
| 14 | 204:30 | 550 | 540 | 5.340 | 6.346 | 0.108 | 0.164 |
| | 206:30 | 60000 | 3360 | 4.779 | 5.919 | 0.307 | 0.320 |
| 15 | 208:30 | 650 | 540 | 5.335 | 6.340 | 0.111 | 0.169 |
| | 210:30 | 60000 | 3350 | 4.771 | 5.912 | 0.312 | 0.326 |
| 16 | 212:30 | 650 | 540 | 5.331 | 6.336 | 0.115 | 0.171 |
| | 214:30 | 60000 | 3340 | 4.764 | 5.907 | 0.316 | 0.329 |
| 17 | 216:30 | 1050 | 560 | 5.315 | 6.324 | 0.121 | 0.176 |
| | 218:30 | 60000 | 3340 | 4.757 | 5.900 | 0.319 | 0.332 |
| 18 | 220:30 | 950 | 540 | 5.316 | 6.324 | 0.122 | 0.177 |
| | 222:30 | 60000 | 3340 | 4.750 | 5.897 | 0.324 | 0.335 |
| 19 | 224:30 | 600 | 540 | 5.311 | 6.321 | 0.126 | 0.180 |
| | 226:30 | 60000 | 3360 | 4.745 | 5.890 | 0.328 | 0.339 |
| 20 | 228:30 | 600 | 550 | 5.313 | 6.321 | 0.126 | 0.181 |
| | 230:30 | 60000 | 3350 | 4.741 | 5.886 | 0.329 | 0.340 |
| | 231:30 | 65000 | 3520 | 4.696 | 5.853 | 0.355 | 0.361 |
| | 232:30 | " | " | 4.690 | 5.848 | 0.359 | 0.365 |
| | 233:30 | " | " | 4.686 | 5.845 | 0.362 | 0.368 |
| | 234:30 | " | " | 4.684 | 5.842 | 0.364 | 0.369 |
| | 235:30 | " | " | 4.682 | 5.841 | 0.365 | 0.370 |
| | 236:30 | " | " | 4.681 | 5.840 | 0.366 | 0.372 |
| | 237:30 | 70000 | 3720 | [illegible] | 5.810 | 0.387 | 0.387 |
| | 238:30 | " | | 4.630 | 5.797 | [illegible] | 0.391 |
| | 239:30 | " | | 4.627 | 5.794 | 0.395 | 0.394 |

..NEL SITE
PILE LOAD TEST DATA

Continuation of: Date: 1-7-87

| Time | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (in) (5.521) | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (in) (0.036) |
|---|---|---|---|---|---|---|
| min:sec | | | | | | |
| 240:30 | 70000 | 3720 | 4.635 | 5.792 | 0.397 | 0.396 |
| 241:30 | " | 3700 | 4.632 | 5.790 | 0.398 | 0.397 |
| 242:30 | " | " | 4.631 | 5.788 | 0.400 | 0.399 |
| 243:30 | 75000 | 3920 | 4.591 | 5.756 | 0.422 | 0.417 |
| 244:30 | " | " | 4.583 | 5.751 | 0.428 | 0.422 |
| 245:30 | " | " | 4.578 | 5.747 | 0.431 | 0.425 |
| 246:30 | " | " | 4.575 | 5.744 | 0.434 | 0.427 |
| 247:30 | " | " | 4.573 | 5.742 | 0.436 | 0.429 |
| 248:30 | " | " | 4.570 | 5.740 | 0.438 | 0.430 |
| 249:30 | 80000 | 4200 | 4.529 | 5.703 | 0.463 | 0.450 |
| 250:30 | " | " | 4.518 | 5.695 | 0.471 | 0.457 |
| 251:30 | " | 4220 | 4.514 | 5.692 | 0.474 | 0.460 |
| 252:30 | " | " | 4.510 | 5.689 | 0.477 | 0.462 |
| 253:30 | " | 4200 | 4.507 | 5.687 | 0.479 | 0.464 |
| 254:30 | " | " | 4.505 | 5.684 | 0.481 | 0.461 |
| 255:30 | 85000 | 4450 | 4.460 | 5.649 | 0.507 | 0.487 |
| 256:30 | " | 4440 | 4.450 | 5.640 | 0.515 | 0.494 |
| 257:30 | " | " | 4.443 | 5.634 | 0.519 | 0.497 |
| 258:30 | " | " | 4.439 | 5.630 | 0.522 | 0.500 |
| 259:30 | " | " | 4.435 | 5.627 | 0.525 | 0.503 |
| 260:30 | " | " | 4.432 | 5.625 | 0.527 | 0.505 |
| 261:30 | 90000 | 4690 | 4.390 | 5.583 | 0.554 | 0.526 |
| 262:30 | " | " | 4.378 | 5.571 | 0.563 | 0.534 |
| 263:30 | " | " | 4.372 | 5.566 | 0.568 | 0.538 |
| 264:30 | " | " | 4.366 | 5.561 | 0.572 | 0.541 |
| 265:30 | " | " | 4.362 | 5.558 | 0.575 | 0.545 |
| 266:30 | " | " | 4.359 | 5.555 | 0.578 | 0.547 |
| 267:30 | 95000 | 4800 | 4.312 | 5.512 | 0.605 | 0.569 |
| 268:30 | " | " | 4.300 | 5.505 | 0.613 | 0.577 |
| 269:30 | " | " | 4.292 | 5.497 | 0.619 | 0.561 |
| 270:30 | " | " | 4.286 | 5.493 | 0.623 | 0.585 |
| 271:30 | " | " | 4.281 | 5.489 | 0.627 | 0.588 |
| 272:30 | " | " | 4.277 | 5.485 | 0.630 | 0.590 |
| 273:30 | 100000 | 5000 | 4.234 | 5.440 | 0.656 | 0.611 |
| 274:30 | " | " | 4.219 | 5.427 | 0.668 | 0.620 |
| 275:30 | " | " | 4.209 | 5.420 | 0.674 | 0.626 |
| 276:30 | " | 5040 | 4.202 | 5.414 | 0.679 | 0.630 |
| 277:30 | " | " | 4.196 | 5.409 | 0.683 | 0.634 |
| 278:30 | " | 5060 | 4.192 | 5.405 | 0.686 | 0.636 |
| 279:30 | 105000 | 5320 | 4.151 | 5.368 | 0.709 | 0.655 |
| 280:30 | " | 5340 | 4.128 | 5.350 | 0.724 | 0.669 |
| 281:30 | " | 5350 | 4.117 | 5.340 | 0.732 | 0.675 |

TUNNEL SITE
PILE LOAD TEST DATA

Continuation of: Pipe Pile Date: 1-7-87

| Time | Load Cell Reading | Pressure in Jack | Test Pile Disp. | | Reaction Pile Disp. | |
|---|---|---|---|---|---|---|
| | (lbs.) | | #1 | #2 | #3 | #4 |
| min-sec | | (psi) | (in) | (in) | (in) | (in) |
| 282:30 | 105000 | 5350 | 4.110 | 5.334 | 0.738 | 0.680 |
| 283:30 | " | " | 4.104 | 5.330 | 0.741 | 0.682 |
| 284:30 | " | " | 4.099 | 5.325 | 0.745 | 0.685 |
| 285:30 | 110000 | 5500 | 4.044 | 5.278 | 0.775 | 0.709 |
| 286:30 | " | " | 4.024 | 5.264 | 0.788 | 0.720 |
| 287:30 | " | " | 4.014 | 5.255 | 0.795 | 0.727 |
| 288:30 | " | 5600 | 4.005 | 5.248 | 0.802 | 0.731 |
| 289:30 | " | " | 4.000 | 5.244 | 0.805 | 0.735 |
| 290:30 | " | " | 3.995 | 5.240 | 0.809 | 0.738 |
| 291:30 | 115000 | 5800 | 3.943 | 5.196 | 0.835 | 0.759 |
| 292:30 | " | " | 3.923 | 5.181 | 0.851 | 0.771 |
| 293:30 | " | " | 3.910 | 5.170 | 0.860 | 0.779 |
| 294:30 | " | 5780 | 3.900 | 5.161 | 0.864 | 0.783 |
| 295:30 | " | " | 3.892 | 5.155 | 0.870 | 0.787 |
| 296:30 | " | " | 3.886 | 5.150 | 0.875 | 0.791 |
| 297:30 | 120000 | 6000 | 3.841 | 5.095 | 0.903 | 0.813 |
| 298:30 | " | " | 3.816 | 5.076 | 0.919 | 0.827 |
| 299:30 | " | 6050 | 3.803 | 5.065 | 0.928 | 0.835 |
| 300:30 | " | 6080 | 3.793 | 5.056 | 0.933 | 0.840 |
| 301:30 | " | " | 3.783 | 5.048 | 0.939 | 0.844 |
| 302:30 | " | 6100 | 3.775 | 5.042 | 0.945 | 0.849 |
| 303:30 | 125000 | 6300 | 3.722 | 4.995 | 0.972 | 0.872 |
| 304:30 | " | " | 3.707 | 4.980 | 0.985 | 0.881 |
| 305:30 | " | " | 3.693 | 4.968 | 0.994 | 0.889 |
| 306:30 | " | " | 3.683 | 4.960 | 1.001 | 0.895 |
| 307:30 | " | " | 3.672 | 4.951 | 1.007 | 0.901 |
| 308:30 | " | " | 3.665 | 4.945 | 1.012 | 0.906 |
| 309:30 | 130000 | 6500 | 3.606 | 4.896 | 1.040 | 0.938 |
| 310:30 | " | " | 3.583 | 4.875 | 1.057 | 0.951 |
| 311:30 | " | " | 3.569 | 4.862 | 1.064 | 0.958 |
| 312:30 | " | " | 3.558 | 4.853 | 1.071 | 0.964 |
| 313:30 | " | " | 3.548 | 4.844 | 1.078 | 0.969 |
| 314:30 | " | " | 3.540 | 4.838 | 1.083 | 0.972 |
| 315:30 | 135000 | 6680 | 3.479 | 4.786 | 1.111 | 1.000 |
| 316:30 | " | 6700 | 3.457 | 4.768 | 1.131 | 1.014 |
| 317:30 | " | " | 3.442 | 4.756 | 1.140 | 1.022 |
| 318:30 | " | " | 3.428 | 4.742 | 1.149 | 1.029 |
| 319:30 | " | " | 3.416 | 4.733 | 1.155 | 1.034 |
| 320:30 | " | 6720 | 3.408 | 4.725 | 1.162 | 1.039 |
| 321:30 | 140000 | 7000 | 3.354 | 4.680 | 1.186 | 1.062 |
| 322:30 | " | 7020 | 3.325 | 4.656 | 1.207 | 1.074 |
| 323:30 | " | " | 3.309 | 4.644 | 1.217 | 1.088 |

Concrete shaft

pipe pile

17:13

TUNNEL SITE
PILE LOAD TEST DATA

Continuation of: Date:

Pile Cap [illegible]
6 Ft
behind pipe pile

0.5 in → 1 in
after unload
pipe pile
was perma-
nently bent

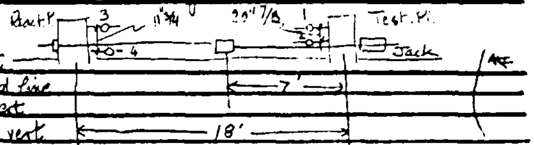
| Time (mn:sec) | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (in) -6.321 | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (in) |
|---|---|---|---|---|---|---|
| 324:30 | 140000 | 7020 | 3.299 | 4.624 | 1.226 | 1.095 |
| 325:30 | " | 7040 | 3.288 | 4.616 | 1.233 | 1.101 |
| 326:30 | " | " | 3.280 | 4.609 | 1.239 | 1.106 |
| 327:30 | 145000 | 7250 | 3.217 | 4.550 | 1.273 | 1.137 |
| 328:30 | " | 7240 | 3.191 | 4.530 | 1.286 | 1.152 |
| 329:30 | " | 7220 | 3.174 | 4.514 | 1.297 | 1.160 |
| 330:30 | " | " | 3.160 | 4.501 | 1.304 | 1.168 |
| 331:30 | " | " | 3.150 | 4.493 | 1.310 | 1.172 |
| 332:30 | " | " | 3.140 | 4.484 | 1.311 | 1.174 |
| 333:30 | 150000 | 7400 | 3.079 | 4.430 | 1.345 | 1.209 |
| 334:30 | " | " | 3.046 | 4.405 | 1.366 | 1.224 |
| 335:30 | " | 7420 | 3.027 | 4.388 | 1.377 | 1.233 |
| 336:30 | " | " | 3.015 | 4.368 | 1.387 | 1.240 |
| 337:30 | " | 7440 | 3.004 | 4.359 | 1.395 | 1.248 |
| 338:30 | " | 7460 | 2.993 | 4.349 | 1.402 | 1.254 |
| 339:30 | 155000 | 7800 | 2.934 | 4.297 | 1.432 | 1.277 |
| 340:30 | " | " | 2.903 | 4.270 | 1.448 | 1.292 |
| 341:30 | " | " | 2.883 | 4.252 | 1.463 | 1.302 |
| 342:30 | " | " | 2.866 | 4.237 | 1.473 | 1.311 |
| 343:30 | " | " | 2.853 | 4.226 | 1.480 | 1.317 |
| 344:30 | " | " | 2.841 | 4.216 | 1.488 | 1.324 |
| 345:30 | 160000 | 8020 | 2.770 | 4.155 | 1.520 | 1.350 |
| 346:30 | " | 8020 | 2.741 | 4.131 | 1.540 | 1.366 |
| 347:30 | " | 8020 | 2.717 | 4.110 | 1.550 | 1.378 |
| 348:30 | " | " | 2.700 | 4.095 | 1.564 | 1.385 |
| 349:30 | " | " | 2.687 | 4.084 | 1.573 | 1.392 |
| 11:40 350:30 | " | 8000 | 2.676 | 4.074 | 1.581 | 1.398 |
| 17:52 [illegible] | 155000 | 7800 | 2.654 | 4.051 | 1.597 | 1.411 |
| | | | | | | |
| | [illegible] | [illegible] | [illegible] | [illegible] -150 | lb. | |

TUNNEL SITE
PILE LOAD TEST DATA

Test Pile: 36" Drilled Shaft / load line = 3.5' above ground line Date: 1-8-87

Reaction Pile: 42" Drilled Shaft / load line = 3.5" above ground line

Displacement gage locations:




#1: 24"3/4 above load line / 2" right of vert

#2: 4"1/4 above load line / vert on load line

#3: 10" above load line / 1" right of vert

#4: 2" below load line / 1" right of vert

| | Time min:Sec | Load Cell Reading (lbs.) | Pressure in Jack | Test Pile Disp. #1 | Test Pile Disp. #2 | Reaction Pile Disp. #3 | Reaction Pile Disp. #4 |
|---|---|---|---|---|---|---|---|
| 10:02 | 0 | – 1500 | 540 | 1.621 | 0.868 | 0.681 | 0.105 |
| | :30 sec | 5000 | 800 | 1.632 | 0.870 | 0.685 | 0.105 |
| | 1:30 | " | " | 1.629 | 0.871 | 0.685 | 0.105 |
| | 2:30 | " | " | 1.630 | 0.871 | 0.685 | 0.105 |
| | 3:30 | " | " | 1.630 | 0.871 | 0.685 | 0.105 |
| | 4:30 | " | " | 1.630 | 0.871 | 0.685 | 0.105 |
| | 5:30 | 10000 | 1020 | 1.643 | 0.882 | 0.692 | 0.106 |
| | 6:30 | " | 1000 | 1.644 | 0.883 | 0.692 | 0.107 |
| | 7:30 | " | " | 1.645 | 0.883 | 0.693 | 0.107 |
| | 8:30 | " | " | 1.645 | 0.884 | 0.693 | 0.107 |
| | 9:30 | " | " | 1.646 | 0.884 | 0.693 | 0.107 |
| | 10:30 | " | " | 1.646 | 0.885 | 0.693 | 0.107 |
| | 11:30 | 15000 | 1240 | 1.661 | 0.897 | 0.701 | 0.111 |
| | 12:30 | " | 1220 | 1.662 | 0.897 | 0.702 | 0.113 |
| | 13:30 | " | " | 1.664 | 0.899 | 0.702 | 0.113 |
| | 14:30 | " | 1240 | 1.665 | 0.899 | 0.702 | 0.113 |
| | 15:30 | " | " | 1.665 | 0.899 | 0.703 | 0.113 |
| | 16:30 | " | " | 1.665 | 0.899 | 0.703 | 0.113 |
| | 17:30 | 20000 | 1500 | 1.682 | 0.912 | 0.712 | 0.120 |
| | 18:30 | " | " | 1.684 | 0.915 | 0.712 | 0.120 |
| | 19:30 | " | " | 1.685 | 0.914 | 0.713 | 0.121 |
| | 20:30 | " | " | 1.685 | 0.914 | 0.713 | 0.121 |
| | 21:30 | " | " | 1.686 | 0.915 | 0.713 | 0.121 |
| | 22:30 | " | " | 1.687 | 0.917 | 0.713 | 0.121 |
| | 23:30 | 25000 | 1720 | 1.705 | 0.931 | 0.723 | 0.128 |
| | 24:30 | " | 1740 | 1.707 | 0.933 | 0.724 | 0.129 |
| | 25:30 | " | " | 1.708 | 0.933 | 0.724 | 0.129 |
| | 26:30 | " | 1720 | 1.709 | 0.934 | 0.725 | 0.129 |
| | 27:30 | " | 1740 | 1.709 | 0.935 | 0.725 | 0.129 |
| | 28:30 | " | 1740 | 1.711 | 0.935 | 0.725 | 0.129 |
| | 29:30 | 30000 | 1940 | 1.730 | 0.951 | 0.736 | 0.139 |
| | 30:30 | " | " | 1.732 | 0.953 | 0.736 | 0.140 |
| | 31:30 | " | 1960 | 1.733 | 0.954 | 0.736 | 0.140 |
| | 32:30 | " | 1950 | 1.735 | 0.956 | 0.739 | 0.141 |
| | 33:30 | " | " | 1.734 | 0.956 | 0.739 | 0.141 |
| | 34:30 | " | " | 1.735 | 0.956 | 0.739 | 0.141 |

TUNNEL SITE
PILE LOAD TEST DATA

Test Pile: Drilled Shaft Date: 1-8-87

Reaction Pile:

Displacement gage locations:
#1:
#2:
#3:
#4:

| Time | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. #1 (in) | Test Pile Disp. #2 (in) ~~0.868~~ | Reaction Pile Disp. #3 (in) | Reaction Pile Disp. #4 (in) (0.105) |
|---|---|---|---|---|---|---|
| 35:30 | 35000 | 2150 | 1.757 | 0.974 | 0.752 | 0.151 |
| 36:30 | " | " | 1.761 | 0.976 | 0.754 | 0.153 |
| 37:30 | " | " | 1.763 | 0.978 | 0.755 | 0.153 |
| 38:30 | " | " | 1.764 | 0.980 | 0.755 | 0.154 |
| 39:30 | " | 2140 | 1.766 | 0.981 | 0.756 | 0.155 |
| 40:30 | " | 2150 | 1.767 | 0.981 | 0.757 | 0.156 |
| 41:30 | 40000 | 2360 | 1.792 | 1.001 | 0.770 | 0.167 |
| 42:30 | " | " | 1.796 | 1.004 | 0.773 | 0.169 |
| 43:30 | " | " | 1.798 | 1.004 | 0.774 | 0.170 |
| 44:30 | " | " | 1.800 | 1.007 | 0.775 | 0.170 |
| 45:30 | " | " | 1.801 | 1.008 | 0.775 | 0.170 |
| 46:30 | " | " | 1.801 | 1.008 | 0.776 | 0.170 |
| 47:30 | " | " | 1.802 | 1.009 | 0.776 | 0.171 |
| 48:30 | 45000 | 2560 | 1.829 | 1.032 | 0.791 | 0.183 |
| 49:30 | " | " | 1.833 | 1.035 | 0.793 | 0.185 |
| 50:30 | " | " | 1.842 | 1.041 | 0.795 | 0.186 |
| 51:30 | " | " | 1.847 | 1.045 | 0.796 | 0.188 |
| 52:30 | " | " | 1.849 | 1.047 | 0.797 | 0.189 |
| 53:30 | " | " | 1.851 | 1.048 | 0.798 | 0.189 |
| 54:30 | 50000 | 2780 | 1.886 | 1.080 | 0.814 | 0.203 |
| 55:30 | " | " | 1.901 | 1.089 | 0.818 | 0.207 |
| 56:30 | " | " | 1.907 | 1.093 | 0.820 | 0.208 |
| 57:30 | " | " | 1.910 | 1.096 | 0.822 | 0.210 |
| 58:30 | " | " | 1.914 | 1.099 | 0.823 | 0.210 |
| 59:30 | " | " | 1.915 | 1.099 | 0.824 | 0.211 |
| 60:30 | 55000 | 3000 | 1.956 | 1.134 | 0.842 | 0.226 |
| 61:30 | " | " | 1.972 | 1.145 | 0.848 | 0.230 |
| 62:30 | " | " | 1.980 | 1.150 | 0.85[illegible] | 0.232 |
| 63:30 | " | " | 1.982 | 1.154 | 0.851 | 0.232 |
| 64:30 | " | " | 1.985 | 1.155 | 0.852 | 0.233 |
| 65:30 | " | " | 1.986 | 1.156 | 0.853 | 0.235 |
| 67:30 | 650 | 580 | 1.751 | 0.969 | 0.738 | 0.173 |
| 69:30 | 55000 | 3080 | 2.006 | 1.182 | 0.864 | 0.262 |
| 71:30 | 600 | 580 | 1.772 | 0.983 | 0.742 | 0.176 |
| 73:30 | 600 | | | | | |
| 75:30 | 55000 | 3080 | 2.036 | 1.199 | 0.869 | 0.267 |

bottom

loss of power to load for 2 min.

TUNNEL SITE
PILE LOAD TEST DATA

Test Pile: ______________________ Date: ____________

Reaction Pile: ______________________

Displacement gage locations:
#1: ______________________
#2: ______________________
#3: ______________________
#4: ______________________

| | Time | Load Cell Reading | Pressure in Jack | Test Pile Disp. | | Reaction Pile Disp. | |
|---|---|---|---|---|---|---|---|
| | | | | #1 | #2 | #3 | #4 |
| | min:sec | (lbs.) | (psi) | (in) | (in) (0.667) | (in) | (in) (0.105) |
| 3 | 77:30 | 600 | 580 | 1.787 | 0.995 | 0.747 | 0.179 |
| | 79:30 | 55000 | 3080 | 2.059 | 1.217 | 0.877 | 0.274 |
| 4 | 81:30 | 600 | 600 | 1.799 | 1.007 | 0.751 | 0.183 |
| | 83:30 | 55000 | 3080 | 2.074 | 1.230 | 0.881 | 0.278 |
| 5 | 85:30 | 550 | 600 | 1.809 | 1.014 | 0.801 ? | 0.189 |
| | 87:30 | 55000 | 3080 | 2.089 | 1.238 | 0.883 | 0.273 |
| 6 | 89:30 | 650 | 600 | 1.818 | 1.022 | 0.756 | 0.169 |
| | 91:30 | 55000 | 3080 | 2.099 | 1.247 | 0.886 | 0.281 |
| 7 | 93:30 | 550 | 580 | 1.826 | 1.027 | 0.759 | 0.190 |
| | 95:30 | 55000 | 3080 | 2.103 | 1.254 | 0.889 | 0.285 |
| 8 | 97:30 | 550 | 580 | 1.831 | 1.031 | 0.761 | 0.192 |
| | 99:30 | 55000 | 3080 | 2.119 | 1.263 | 0.894 | 0.290 |
| 9 | 101:50 | 750 | 600 | 1.840 | 1.040 | 0.765 | 0.196 |
| | 103:30 | 55000 | 3050 | 2.128 | 1.270 | 0.893 | 0.293 |
| 10 | 105:30 | 660 | 600 | 1.842 | 1.043 | 0.767 | 0.198 |
| | 107:30 | 55000 | 3050 | 2.135 | 1.276 | 0.899 | 0.297 |
| 11 | 109:30 | 27650 | 1700 | 2.050 | 1.209 | 0.846 | 0.262 |
| | 111:30 | 55000 | 3050 | 2.143 | 1.284 | 0.903 | 0.299 |
| 12 | 113:30 | 27600 | 1680 | 2.058 | 1.215 | 0.850 | 0.265 |
| | 115:30 | 55000 | 3050 | 2.149 | 1.288 | 0.906 | 0.301 |
| 13 | 117:30 | 27550 | 1700 | 2.064 | 1.221 | 0.853 | 0.267 |
| | 119:30 | 55000 | 3050 | 2.156 | 1.294 | 0.909 | 0.305 |
| 14 | 121:30 | 27550 | 1680 | 2.071 | 1.226 | 0.857 | 0.271 |
| | 123:30 | 55000 | 3060 | 2.160 | 1.297 | 0.911 | 0.307 |
| 15 | 125:30 | 27550 | 1700 | 2.075 | 1.230 | 0.860 | 0.274 |
| | 127:30 | 55000 | 3060 | 2.163 | 1.301 | 0.914 | 0.310 |
| 16 | 129:30 | 27500 | 1700 | 2.065 | 1.222 | 0.856 | 0.270 |
| | 131:30 | 55000 | 3050 | 2.168 | 1.303 | 0.915 | 0.310 |
| 17 | 133:30 | 27600 | 1700 | 2.083 | 1.236 | 0.863 | 0.278 |
| | 135:30 | 55000 | 3050 | 2.173 | 1.307 | 0.917 | 0.311 |
| 18 | 137:30 | 27650 | 1700 | 2.086 | 1.239 | 0.865 | 0.279 |
| | 139:30 | 55000 | 3050 | 2.176 | 1.310 | 0.918 | 0.312 |
| 19 | 141:30 | 27400 | 1700 | 2.090 | 1.243 | 0.867 | 0.281 |
| | 143:30 | 55000 | 3050 | 2.178 | 1.312 | 0.920 | 0.314 |
| 20 | 145:30 | 27600 | 1700 | 2.092 | 1.245 | [illegible] | 0.282 |
| | 147:30 | 55000 | 3050 | 2.182 | 1.314 | 0.922 | 0.317 |

gage sticking ignore this number

# TUNNEL SITE
# PILE LOAD TEST DATA

Test Pile: ______________________ Date: ____________

Reaction Pile: ______________________

Displacement gage locations:
- #1: ______________________
- #2: ______________________
- #3: ______________________
- #4: ______________________

| | Time | Load Cell Reading (lbs.) | Pressure in Jack | Test Pile Disp. | | Reaction Pile Disp. | |
|---|---|---|---|---|---|---|---|
| | | | | #1 (in) | #2 (in) -0.868) | #3 (in) | #4 (in) -0.105) |
| | 148:30 | 60000 | 2280 | 2.203 | 1.333 | 0.936 | 0.328 |
| | 149:30 | 60000 | 3280 | 2.207 | 1.336 | 0.938 | 0.331 |
| | 150:30 | " | " | 2.209 | 1.338 | 0.940 | 0.332 |
| | 151:30 | " | " | 2.211 | 1.339 | 0.941 | 0.332 |
| | 152:30 | " | " | 2.212 | 1.340 | 0.942 | 0.333 |
| | 153:30 | " | " | 2.214 | 1.341 | 0.942 | 0.334 |
| | 154:30 | 65000 | 3480 | 2.239 | 1.362 | 0.957 | 0.346 |
| | 155:30 | " | " | 2.245 | 1.366 | 0.962 | 0.350 |
| | 156:30 | " | " | 2.249 | 1.370 | 0.963 | 0.352 |
| | 157:30 | " | " | 2.251 | 1.371 | 0.965 | 0.353 |
| | 158:30 | " | " | 2.253 | 1.373 | 0.966 | 0.354 |
| | 159:30 | " | " | 2.254 | 1.375 | 0.967 | 0.355 |
| | 160:30 | 70000 | 3680 | 2.285 | 1.398 | 0.984 | 0.370 |
| | 161:30 | " | " | 2.295 | 1.404 | 0.988 | 0.374 |
| | 162:30 | " | " | 2.299 | 1.406 | 0.992 | 0.378 |
| | 163:30 | " | " | 2.300 | 1.409 | 0.993 | 0.378 |
| | 164:30 | " | " | 2.303 | 1.411 | 0.994 | 0.378 |
| | 165:30 | " | " | 2.305 | 1.413 | 0.995 | 0.379 |
| | 166:30 | 75000 | 3900 | 2.340 | 1.444 | 1.015 | 0.396 |
| | 167:30 | " | " | 2.349 | 1.450 | 1.019 | 0.400 |
| | 168:30 | " | " | 2.353 | 1.454 | 1.022 | 0.402 |
| | 169:30 | " | " | 2.356 | 1.456 | 1.024 | 0.404 |
| | 170:30 | " | " | 2.261 | 1.460 | 1.026 | 0.406 |
| | 171:30 | " | " | 2.365 | 1.462 | 1.028 | 0.407 |
| | 172:30 | 80000 | 4120 | 2.404 | 1.495 | 1.048 | 0.424 |
| | 173:30 | " | 4150 | 2.418 | 1.504 | 1.054 | 0.426 |
| | 174:30 | " | 4160 | 2.425 | 1.509 | 1.057 | 0.431 |
| | 175:30 | " | " | 2.431 | 1.513 | 1.060 | 0.433 |
| | 176:30 | " | " | 2.435 | 1.518 | 1.062 | 0.435 |
| | 177:30 | " | " | 2.438 | 1.521 | 1.063 | 0.437 |
| [illegible] 1 | 178:30 | 40000 | 2180 | 2.315 | 1.420 | 0.982 | 0.382 |
| | 180:30 | 80000 | 4180 | 2.457 | 1.544 | 1.077 | 0.452 |
| 2 | 182:30 | 40100 | 2200 | 2.334 | 1.438 | 0.990 | 0.390 |
| | 184:30 | 80000 | 4200 | 2.486 | 1.562 | 1.086 | 0.460 |
| 3 | 186:30 | 40100 | 2200 | 2.357 | 1.456 | 1.000 | 0.398 |
| | 188:30 | 80090 | 4180 | 2.505 | 1.577 | 1.094 | 0.468 |

TUNNEL SITE
PILE LOAD TEST DATA

Test Pile: ______________________ Date: ____________

Reaction Pile: ______________________

Displacement gage locations:
#1: ______________________
#2: ______________________
#3: ______________________
#4: ______________________

| | Time | Load Cell Reading (lbs.) | Pressure in Jack (psi) | Test Pile Disp. | | Reaction Pile Disp. | |
|---|---|---|---|---|---|---|---|
| | | | | #1 (in) | #2 (in) | #3 (in) | #4 (in) |
| | min:sec | | | | | | |
| 4 | 190:30 | 40200 | 2180 | 2.374 | 1.472 | 1.008 | 0.404 |
| | 192:30 | 80000 | 4200 | 2.521 | 1.590 | 1.101 | 0.473 |
| 5 | 194:30 | 40000 | 2200 | 2.390 | 1.484 | 1.014 | 0.409 |
| | 196:30 | 80000 | 4180 | 2.536 | 1.602 | 1.108 | 0.480 |
| 6 | 198:30 | 40150 | 2150 | 2.401 | 1.495 | 1.020 | 0.415 |
| | 200:30 | 80000 | 4180 | 2.548 | 1.612 | 1.113 | 0.482 |
| 7 | 202:30 | 40200 | 2160 | 2.415 | 1.511 | 1.026 | 0.420 |
| | 204:30 | 80000 | 4160 | 2.559 | 1.623 | 1.119 | 0.490 |
| 8 | 206:30 | 39850 | 2120 | 2.421 | 1.515 | 1.028 | 0.422 |
| | 208:30 | 80000 | 4180 | 2.568 | 1.630 | 1.123 | 0.492 |
| 9 | 210:30 | 39850 | 2120 | 2.430 | 1.520 | 1.033 | 0.426 |
| | 212:30 | 80000 | 4180 | 2.576 | 1.638 | 1.127 | 0.496 |
| 10 | 214:30 | 40000 | 2150 | 2.442 | 1.529 | 1.038 | 0.431 |
| | 216:30 | 80000 | 4180 | 2.585 | 1.645 | 1.131 | 0.499 |
| 11 | 218:30 | 700 | 500 | 2.050 | 1.213 | 0.880 | 0.303 |
| | 220:30 | 80000 | 4160 | 2.590 | 1.649 | 1.129 | 0.495 |
| 12 | 220:30 | 700 | 500 | 2.055 | 1.225 | 0.882 | 0.306 |
| | 224:30 | 80000 | 4180 | 2.605 | 1.662 | 1.133 | 0.502 |
| 13 | 226:30 | 700 | 500 | 2.066 | 1.236 | 0.888 | 0.311 |
| | 228:30 | 80000 | 4180 | 2.627 | 1.681 | 1.141 | 0.509 |
| 14 | 230:30 | 700 | 500 | 2.073 | 1.243 | 0.891 | 0.313 |
| | 232:30 | 80000 | 4160 | 2.644 | 1.695 | 1.147 | 0.516 |
| 15 | 234:30 | 750 | 500 | 2.088 | 1.255 | 0.897 | 0.319 |
| | 236:30 | 80000 | 4160 | 2.663 | 1.709 | 1.154 | 0.521 |
| 16 | 238:30 | 750 | 500 | 2.094 | 1.261 | 0.902 | 0.322 |
| | 240:30 | 80000 | 4160 | 2.675 | 1.722 | 1.158 | 0.523 |
| 17 | 242:30 | 700 | 500 | 2.102 | 1.268 | 0.904 | 0.325 |
| | 244:30 | 80000 | 4160 | 2.685 | 1.728 | 1.159 | 0.525 |
| 18 | 246:30 | 700 | 500 | 2.103 | 1.270 | 0.907 | 0.329 |
| | 248:30 | 80000 | 4160 | 2.700 | 1.740 | 1.165 | 0.527 |
| 19 | 250:30 | 800 | 500 | 2.117 | 1.282 | 0.912 | 0.334 |
| | 252:30 | 80000 | 4160 | 2.704 | 1.750 | 1.169 | 0.531 |
| 20 | 254:30 | 750 | 500 | 2.122 | 1.286 | 0.911 | 0.337 |
| | 256:30 | 80000 | 4140 | 2.712 | 1.761 | 1.172 | 0.535 |
| | 257:30 | 85000 | 4370 | 2.757 | 1.792 | 1.194 | 0.554 |
| | 258:30 | " | " | 2.758 | 1.798 | 1.198 | 0.558 |

TUNNEL SITE
PILE LOAD TEST DATA

Test Pile: ______________________ Date: ____________

Reaction Pile: ______________________

Displacement gage locations:

#1: ______________________

#2: ______________________

#3: ______________________

#4: ______________________

| Time | Load Cell Reading (lbs.) | Pressure in Jack | Test Pile Disp. | | Reaction Pile Disp. | |
|---|---|---|---|---|---|---|
| | | | #1 | #2 | #3 | #4 |
| 259:30 | 85000 | 4320 | 2.763 | 1.801 | 1.201 | 0.560 |
| 260:30 | " | " | 2.766 | 1.803 | 1.203 | 0.561 |
| 261:30 | " | " | 2.768 | 1.805 | 1.204 | 0.563 |
| 262:30 | " | " | 2.769 | 1.806 | 1.206 | 0.564 |
| 263:30 | 90000 | 4560 | 2.800 | 1.831 | 1.223 | 0.578 |
| 264:30 | " | 4540 | 2.806 | 1.835 | 1.226 | 0.581 |
| 265:30 | " | 4560 | 2.810 | 1.839 | 1.229 | 0.583 |
| 266:30 | " | " | 2.813 | 1.842 | 1.232 | 0.585 |
| 267:30 | " | " | 2.816 | 1.843 | 1.233 | 0.587 |
| 268:30 | " | 4580 | 2.817 | 1.845 | 1.234 | 0.587 |
| 269:30 | 95000 | 4800 | 2.849 | 1.870 | 1.252 | 0.601 |
| 270:30 | " | " | 2.857 | 1.877 | 1.257 | 0.607 |
| 271:30 | " | " | 2.861 | 1.880 | 1.259 | 0.608 |
| 272:30 | " | " | 2.865 | 1.883 | 1.262 | 0.610 |
| 273:30 | " | " | 2.868 | 1.885 | 1.263 | 0.611 |
| 274:30 | " | " | 2.870 | 1.888 | 1.265 | 0.613 |
| 275:30 | 100 000 | 5020 | 2.904 | 1.913 | 1.283 | 0.628 |
| 276:30 | " | 5000 | 2.914 | 1.922 | 1.289 | 0.633 |
| 277:30 | " | " | 2.91[illegible] | 1.926 | 1.292 | 0.636 |
| 278:30 | " | 5020 | 2.923 | 1.930 | 1.295 | 0.638 |
| 279:30 | " | 5040 | 2.927 | 1.932 | 1.297 | 0.639 |
| 280:30 | " | " | 2.930 | 1.935 | 1.298 | 0.641 |
| 281:30 | 105 000 | 5240 | 2.963 | 1.964 | 1.316 | 0.657 |
| 282:30 | " | 5250 | 2.976 | 1.973 | 1.324 | 0.662 |
| 283:30 | " | " | 2.981 | 1.977 | 1.326 | 0.665 |
| 284:30 | " | " | 2.981 | 1.987 | 1.330 | 0.668 |
| 285:30 | " | 5260 | 2.991 | 1.985 | 1.332 | 0.671 |
| 286:30 | " | 5240 | 2.995 | 1.988 | 1.335 | 0.673 |
| 287:30 | 110 000 | 5450 | 3.033 | 2.018 | 1.355 | 0.690 |
| 288:30 | " | " | 3.045 | 2.027 | 1.361 | 0.694 |
| 289:30 | " | " | 3.055 | 2.034 | 1.366 | 0.698 |
| 290:30 | " | " | 3.059 | 2.037 | 1.368 | 0.700 |
| 291:30 | " | " | 3.063 | 2.041 | 1.372 | 0.704 |
| 292:30 | " | " | 3.067 | 2.044 | 1.375 | 0.708 |
| 293:30 | 115 000 | 5620 | 3.107 | 2.077 | 1.395 | 0.725 |
| 294:30 | " | " | 3.121 | 2.087 | 1.402 | 0.730 |

| Time min : sec | Load lb | Press. Jack psi | Gage 1 (in) | Gage 2 (in) | Gage 3 (in) | Gage 4 (in) | Comp. Depth |
|---|---|---|---|---|---|---|---|
| 295:30 | 115000 | 5620 | 3.129 | 2.094 | 1.406 | 0.733 | 45 [illegible]/8" |
| 296:30 | " | " | 3.136 | 2.098 | 1.410 | 0.737 | |
| 297:30 | " | " | 3.141 | 2.102 | 1.412 | 0.738 | |
| 298:30 | " | 5800 | 3.145 | 2.105 | 1.416 | 0.741 | |
| 299:30 | 120000 | 5820 | 3.183 | 2.136 | 1.435 | 0.758 | |
| 300:30 | " | " | 3.199 | 2.147 | 1.443 | 0.765 | |
| 301:30 | " | 5850 | 3.208 | 2.155 | 1.448 | 0.768 | |
| 302:30 | " | 5860 | 3.214 | 2.160 | 1.452 | 0.771 | |
| 303:30 | " | 5880 | 3.221 | 2.166 | 1.456 | 0.776 | |
| 304:30 | " | " | 3.226 | 2.169 | 1.459 | 0.780 | |
| 305:30 | 125000 | 6100 | 3.263 | 2.200 | 1.480 | 0.796 | |
| 306:30 | " | " | 3.281 | 2.212 | 1.488 | 0.802 | |
| 307:30 | " | 6120 | 3.294 | 2.222 | 1.493 | 0.807 | |
| 308:30 | " | 6200 | 3.301 | 2.228 | 1.498 | 0.811 | |
| 309:30 | " | " | 3.307 | 2.232 | 1.502 | 0.814 | |
| 310:30 | " | " | 3.312 | 2.236 | 1.504 | 0.816 | |
| 311:30 | 130000 | 6420 | 3.355 | 2.270 | 1.527 | 0.834 | |
| 312:30 | " | " | 3.373 | 2.283 | 1.535 | 0.842 | |
| 313:30 | " | " | 3.384 | 2.292 | 1.541 | 0.848 | |
| 314:30 | " | 6440 | 3.393 | 2.300 | 1.546 | 0.852 | |
| 315:30 | " | " | 3.401 | 2.305 | 1.550 | 0.855 | |
| 316:30 | " | " | 3.406 | 2.309 | 1.553 | 0.858 | |
| 317:30 | 135000 | 6660 | 3.438 | 2.348 | 1.576 | 0.877 | |
| 318:30 | " | 6680 | 3.454 | 2.360 | 1.584 | 0.883 | |
| 319:30 | " | " | 3.467 | 2.370 | 1.591 | 0.891 | |
| 320:30 | " | " | 3.477 | 2.378 | 1.596 | 0.896 | |
| 321:30 | " | 6660 | 3.483 | 2.387 | 1.600 | 0.900 | |
| 322:30 | " | 6650 | 3.489 | 2.394 | 1.604 | 0.902 | |
| 323:30 | 140000 | 6850 | 3.534 | 2.430 | 1.625 | 0.920 | |

| Time mm:sec | Load lbs | Press. Jack psi | Gage 1 in | Gage 2 in | Gage 3 in | Gage 4 in |
|---|---|---|---|---|---|---|
| 324:30 | " | 6850 | 3.555 | 2.445 | 1.636 | 0.930 |
| 325:30 | " | 6840 | 3.566 | 2.454 | 1.643 | 0.935 |
| 326:30 | " | 6820 | 3.576 | 2.462 | 1.648 | 0.939 |
| 327:30 | " | 6820 | 3.580 | 2.470 | 1.652 | 0.943 |
| 328:30 | " | " | 3.587 | 2.475 | 1.656 | 0.946 |
| 329:30 | 145000 | 7080 | 3.694 | 2.554 | 1.678 | 0.965 |
| 330:30 | " | 7100 | 3.718 | 2.571 | 1.690 | 0.976 |
| 331:30 | " | " | 3.732 | 2.582 | 1.697 | 0.981 |
| 332:30 | " | " | 3.740 | 2.600 | 1.702 | 0.986 |
| 333:30 | " | " | 3.747 | 2.608 | 1.708 | 0.990 |
| 334:30 | " | " | 3.754 | 2.614 | 1.711 | 0.992 |
| 335:30 | 150000 | 7340 | 3.793 | 2.668 | 1.735 | 1.013 |
| 336:30 | " | 7360 | 3.815 | 2.684 | 1.746 | 1.023 |
| 337:30 | " | 7380 | 3.832 | 2.694 | 1.754 | 1.029 |
| 338:30 | " | 7480 | 3.840 | 2.704 | 1.761 | 1.035 |
| 339:30 | " | " | 3.850 | 2.710 | 1.765 | 1.038 |
| 340:30 | " | " | 3.859 | 2.718 | 1.769 | 1.041 |
| 341:30 | 155000 | 7620 | 3.905 | 2.758 | 1.790 | 1.060 |
| 342:30 | " | " | 3.924 | 2.775 | 1.801 | 1.069 |
| 343:30 | " | " | 3.943 | 2.792 | 1.809 | 1.076 |
| 344:30 | " | " | 3.950 | 2.799 | 1.815 | 1.082 |
| 345:30 | " | " | 3.962 | 2.806 | 1.821 | 1.087 |
| 346:30 | " | " | 3.971 | 2.814 | 1.826 | 1.090 |
| 347:30 | 160000 | 7800 | 4.025 | 2.858 | 1.851 | 1.111 |
| 348:30 | " | " | 4.047 | 2.875 | 1.862 | 1.120 |
| 349:30 | " | " | 4.067 | 2.890 | 1.871 | 1.126 |
| 350:30 | " | " | 4.075 | 2.904 | 1.880 | 1.13[illegible] |
| 351:30 | " | " | 4.088 | 2.913 | 1.886 | 1.140 |
| 352:30 | " | " | 4.097 | 2.920 | 1.890 | 1.144 |

| Time min:sec | Load (lb) | Press. Jack (psi) | Gage 1 (in) | Gage 2 (in) | Gage 3 (in) | Gage 4 (in) |
|---|---|---|---|---|---|---|
| 353:30 | 165000 | 8050 | 4.151 | 2.967 | 1.915 | 1.168 |
| 354:30 | " | 8060 | 4.179 | 2.988 | 1.928 | 1.176 |
| 355:30 | " | 8100 | 4.200 | 3.003 | 1.937 | 1.184 |
| 356:30 | " | 8100 | 4.214 | 3.013 | 1.943 | 1.189 |
| 357:30 | " | " | 4.225 | 3.023 | 1.950 | 1.195 |
| 358:30 | " | 8120 | 4.236 | 3.032 | 1.955 | 1.199 |
| 359:30 | 170000 | 8350 | 4.288 | 3.082 | 1.979 | 1.220 |
| 360:30 | " | 8360 | 4.320 | 3.105 | 1.993 | 1.231 |
| 361:30 | " | 8380 | 4.338 | 3.119 | 2.001 | 1.236 |
| 362:30 | " | 8400 | 4.355 | 3.133 | 2.008 | 1.244 |
| 363:30 | " | 8400 | 4.373 | 3.147 | 2.015 | 1.250 |
| 364:30 | " | " | 4.384 | 3.156 | 2.021 | 1.255 |
| 365:30 | 175000 | 8600 | 4.443 | 3.205 | 2.043 | 1.275 |
| 366:30 | " | " | 4.482 | 3.234 | 2.057 | 1.286 |
| 367:30 | " | " | 4.516 | 3.258 | 2.068 | 1.295 |
| 16:19 | 74200 | 4800 | 3.854 | 2.876 | 1.725 | 1.047 |

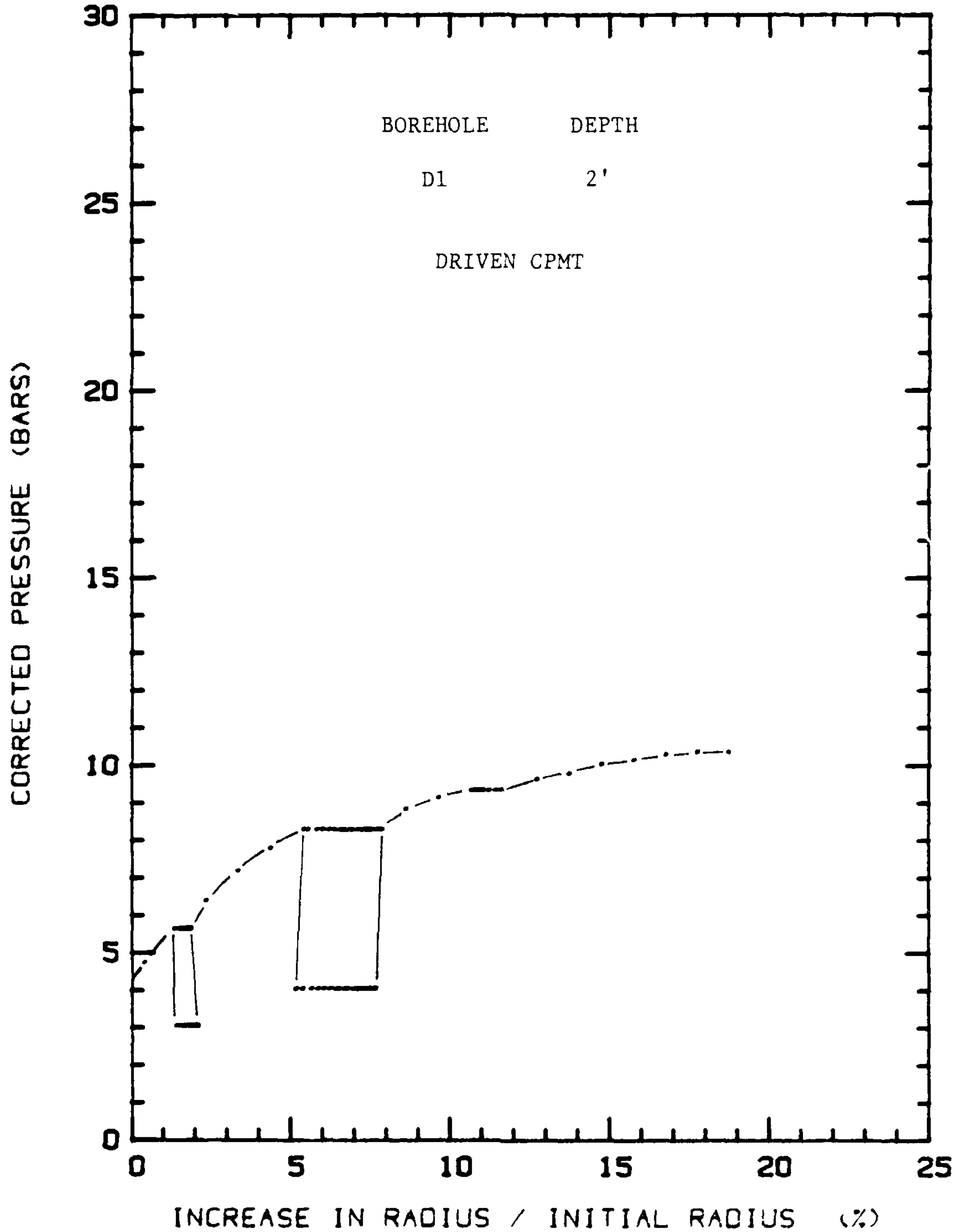
Note: Load Cell and Jack broke!

Gap in back of drilled shaft (36") = 1.25" wide

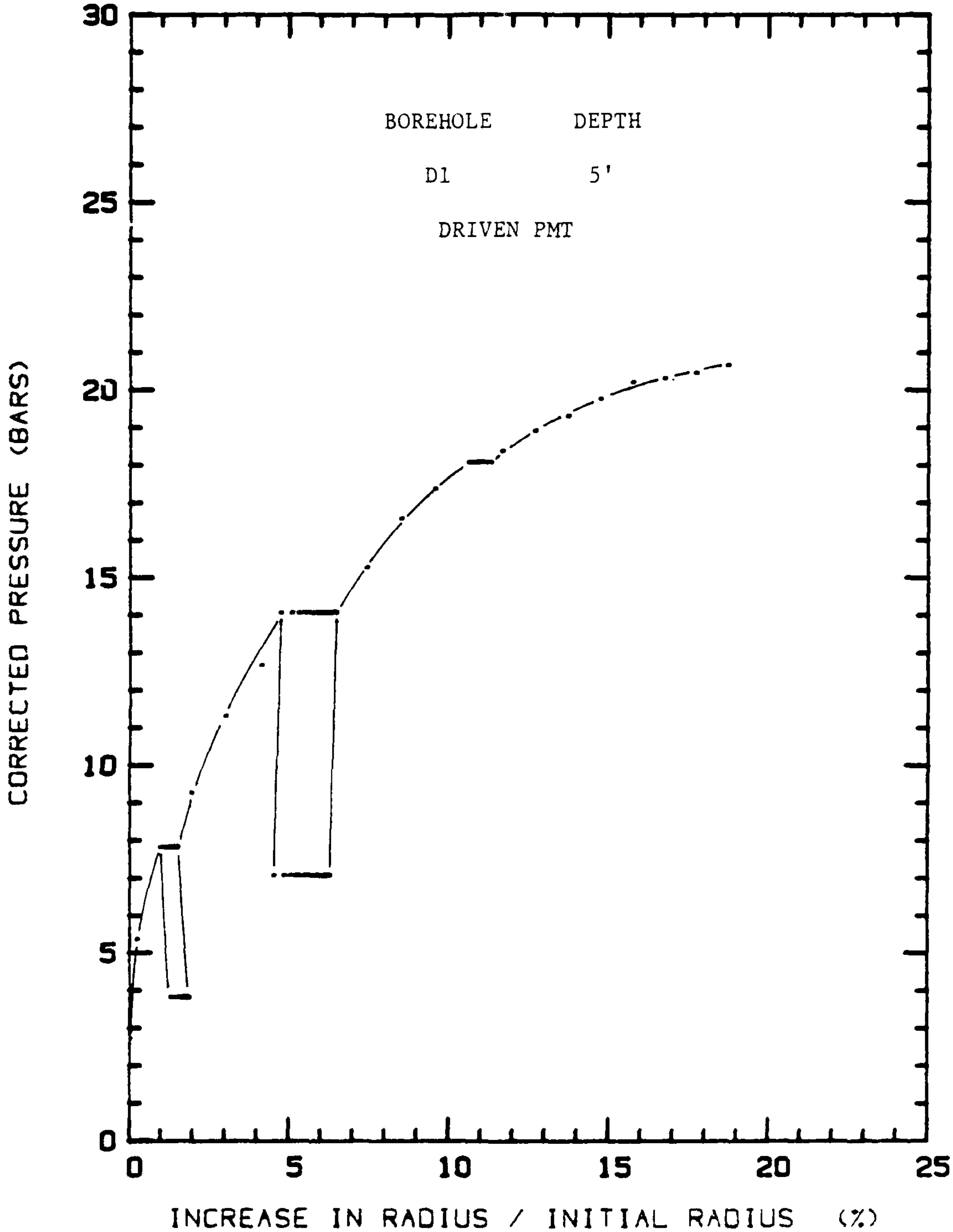
= 45.5/8" deep

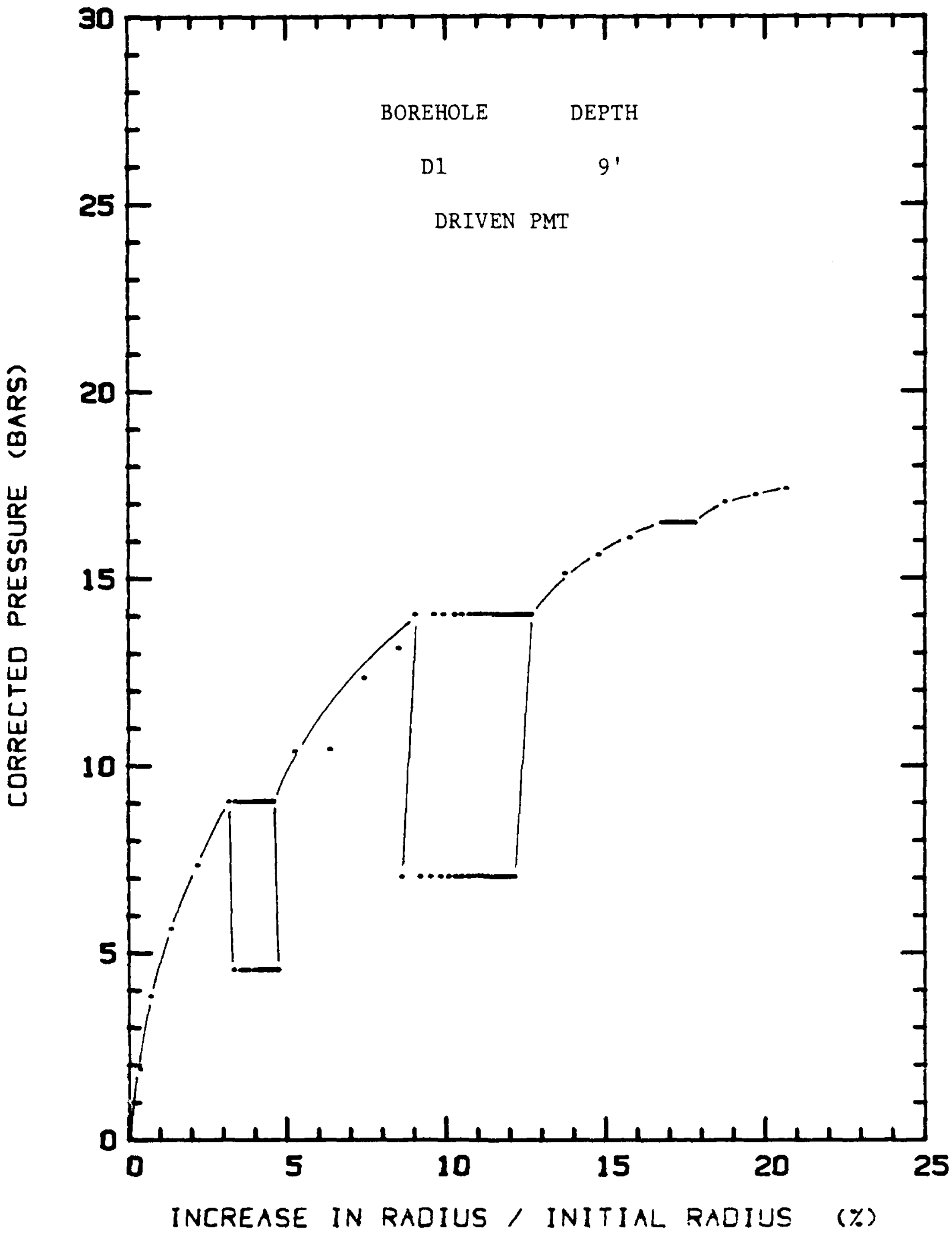
# APPENDIX B

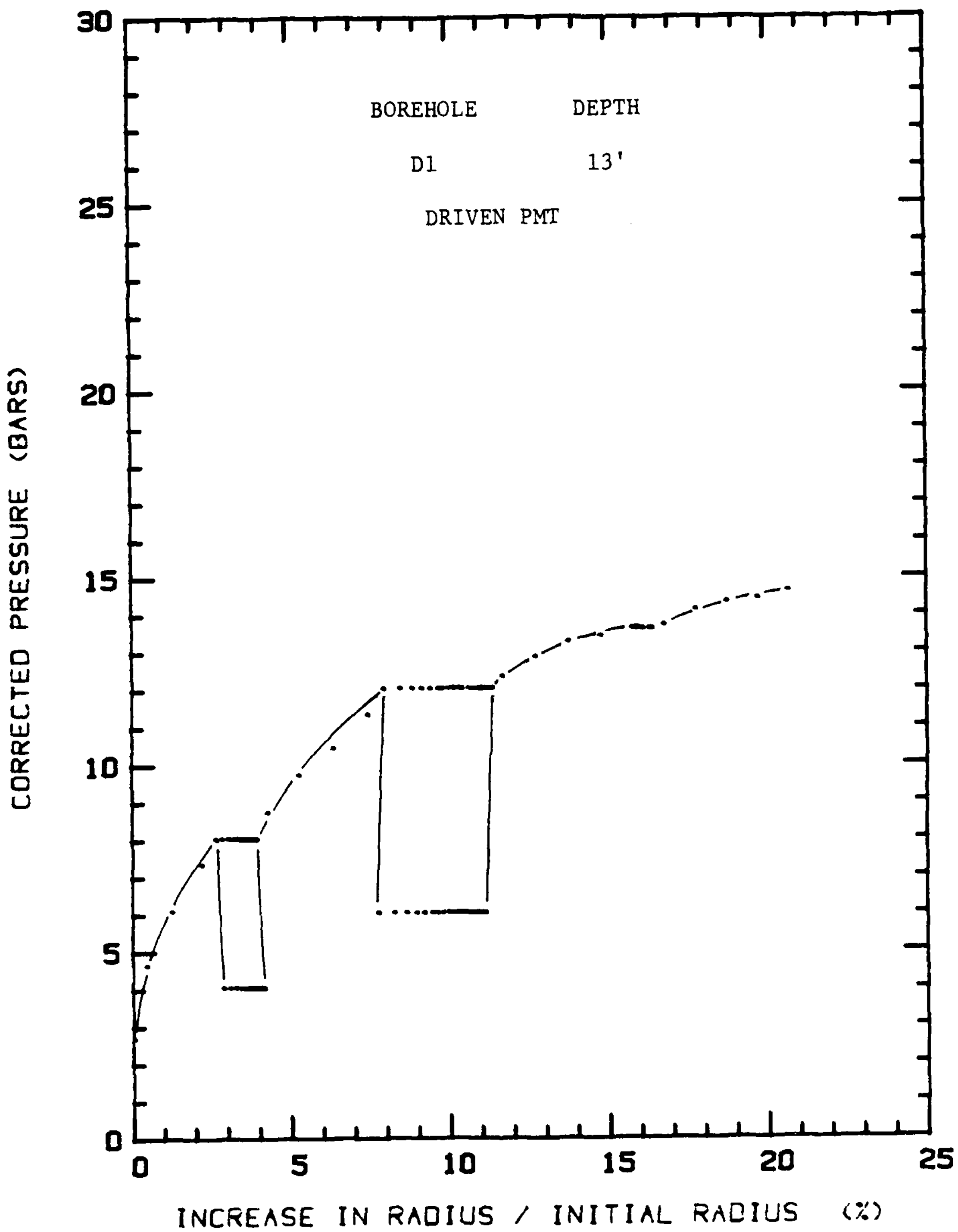
# CORRECTED PMT CURVES

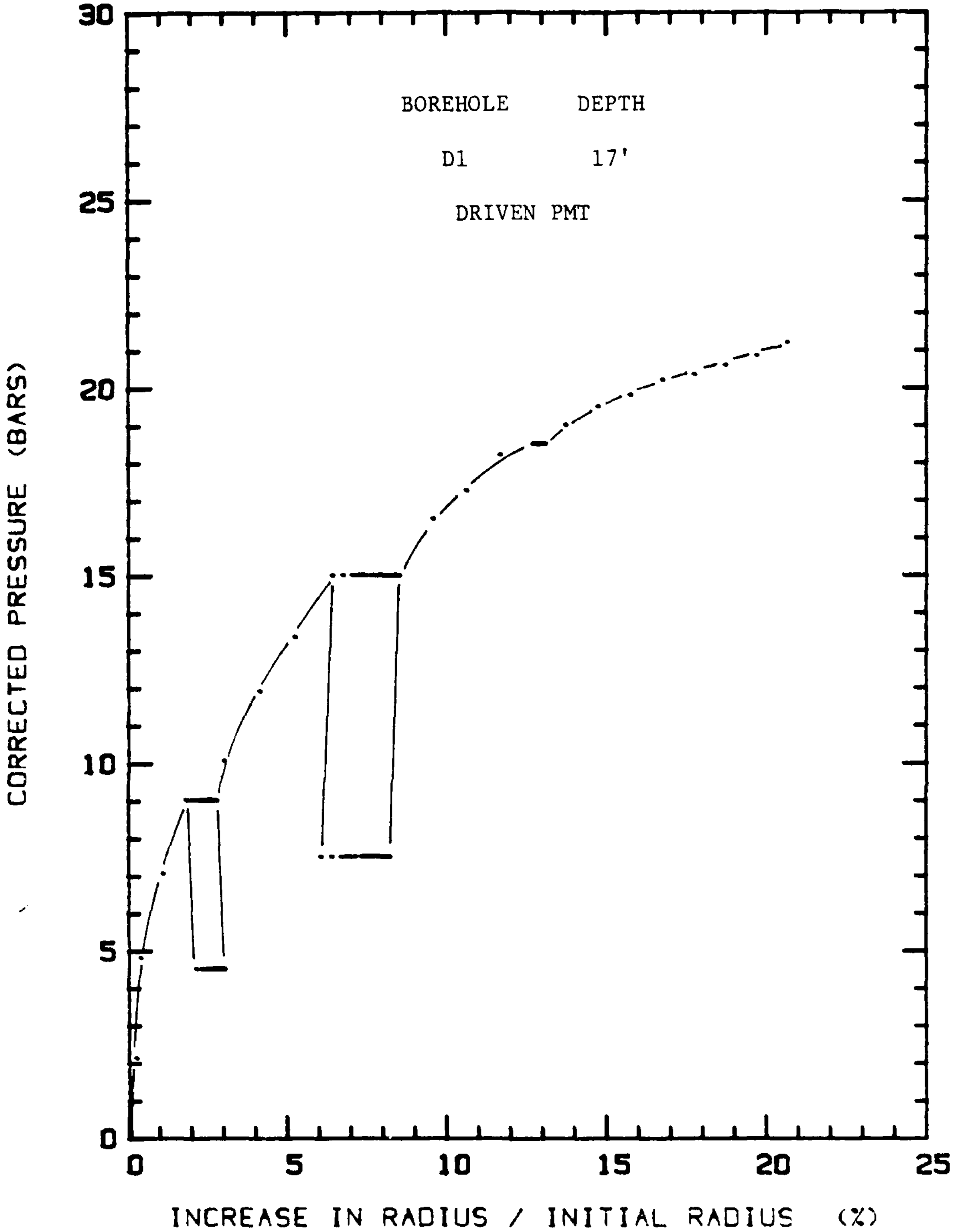


BOREHOLE DEPTH
D1 2'
DRIVEN CPMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
5
10
15
20
25
30

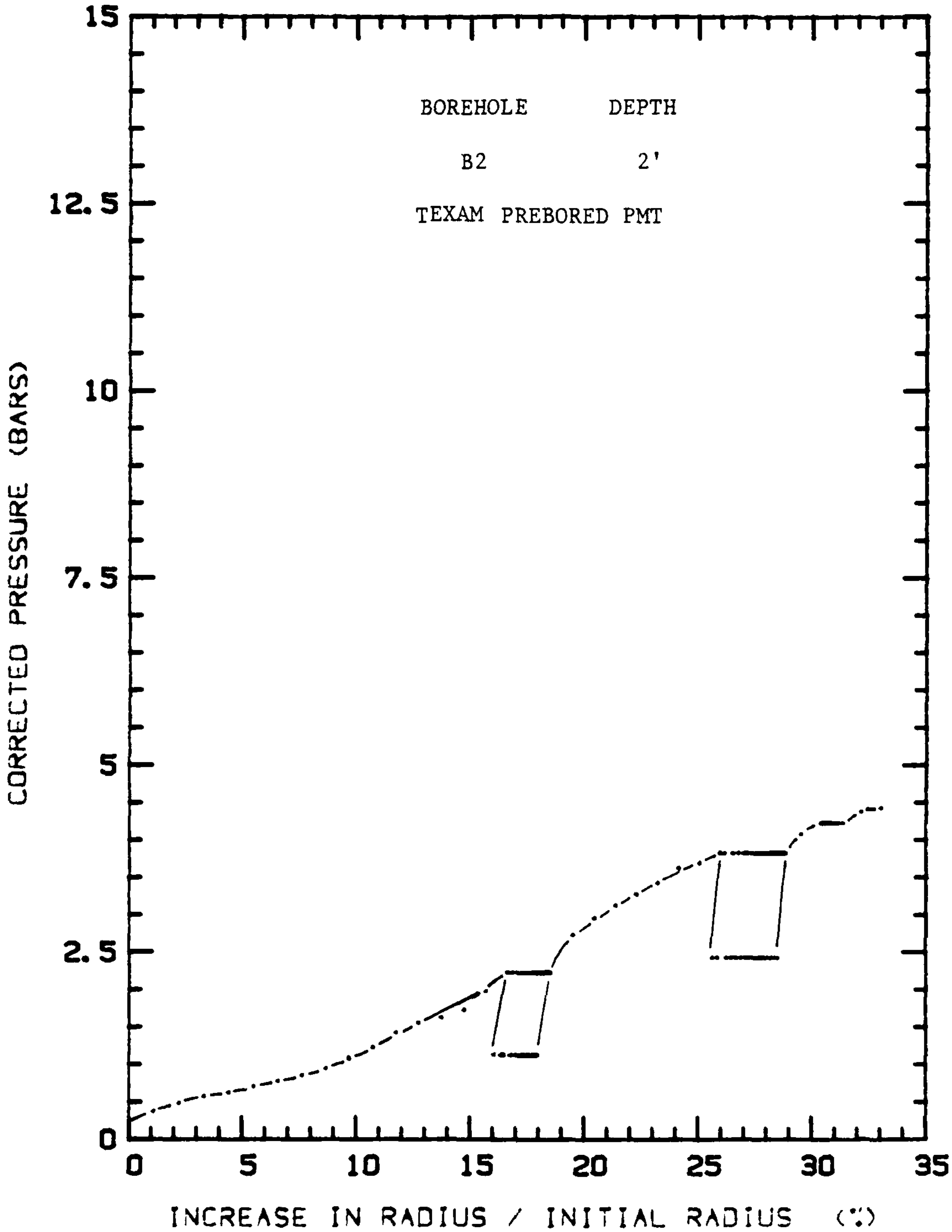

BOREHOLE DEPTH
D1 5'
DRIVEN PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
5
10
15
20
25
30


BOREHOLE DEPTH
D1 9'
DRIVEN PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
5
10
15
20
25
30

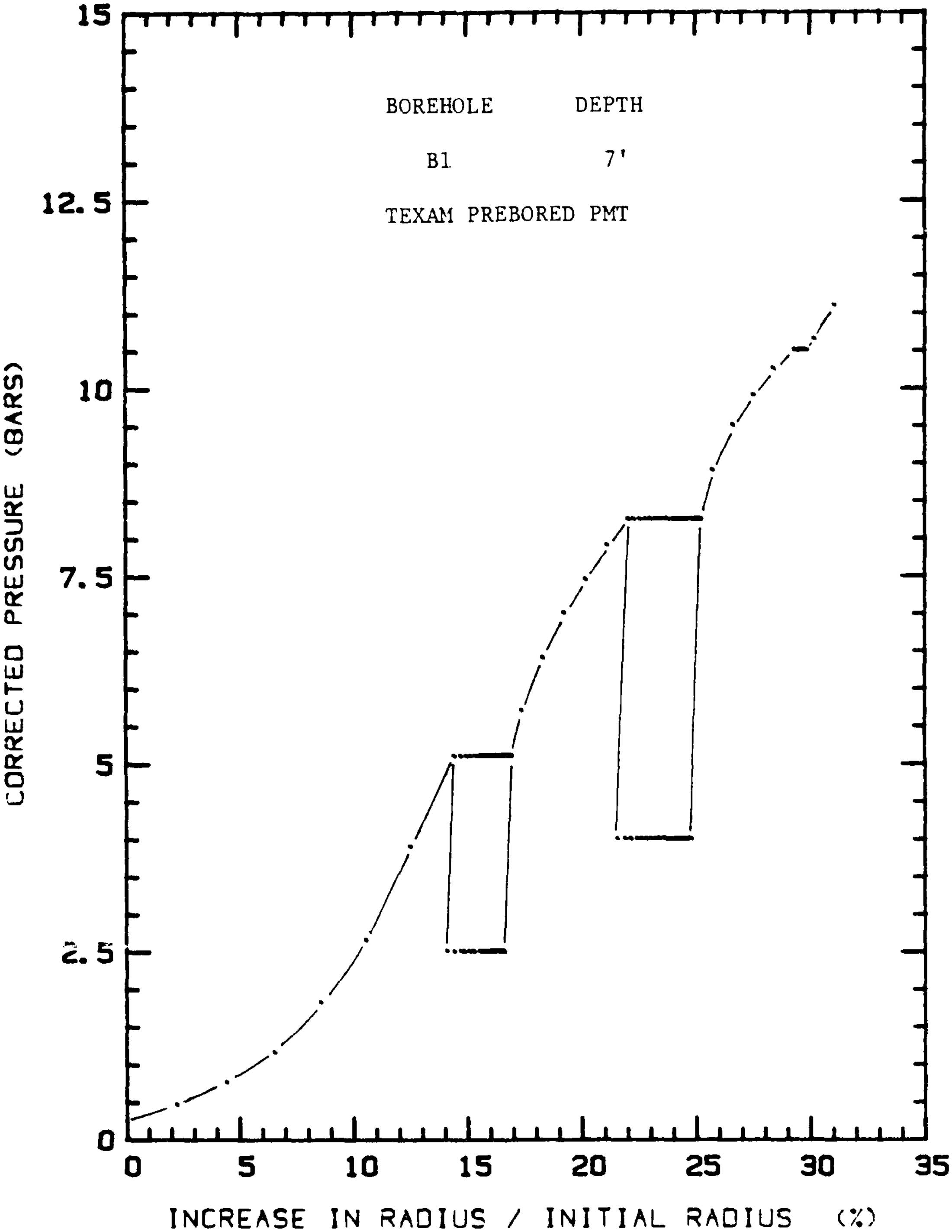

BOREHOLE DEPTH
D1 13'
DRIVEN PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
5
10
15
20
25
30



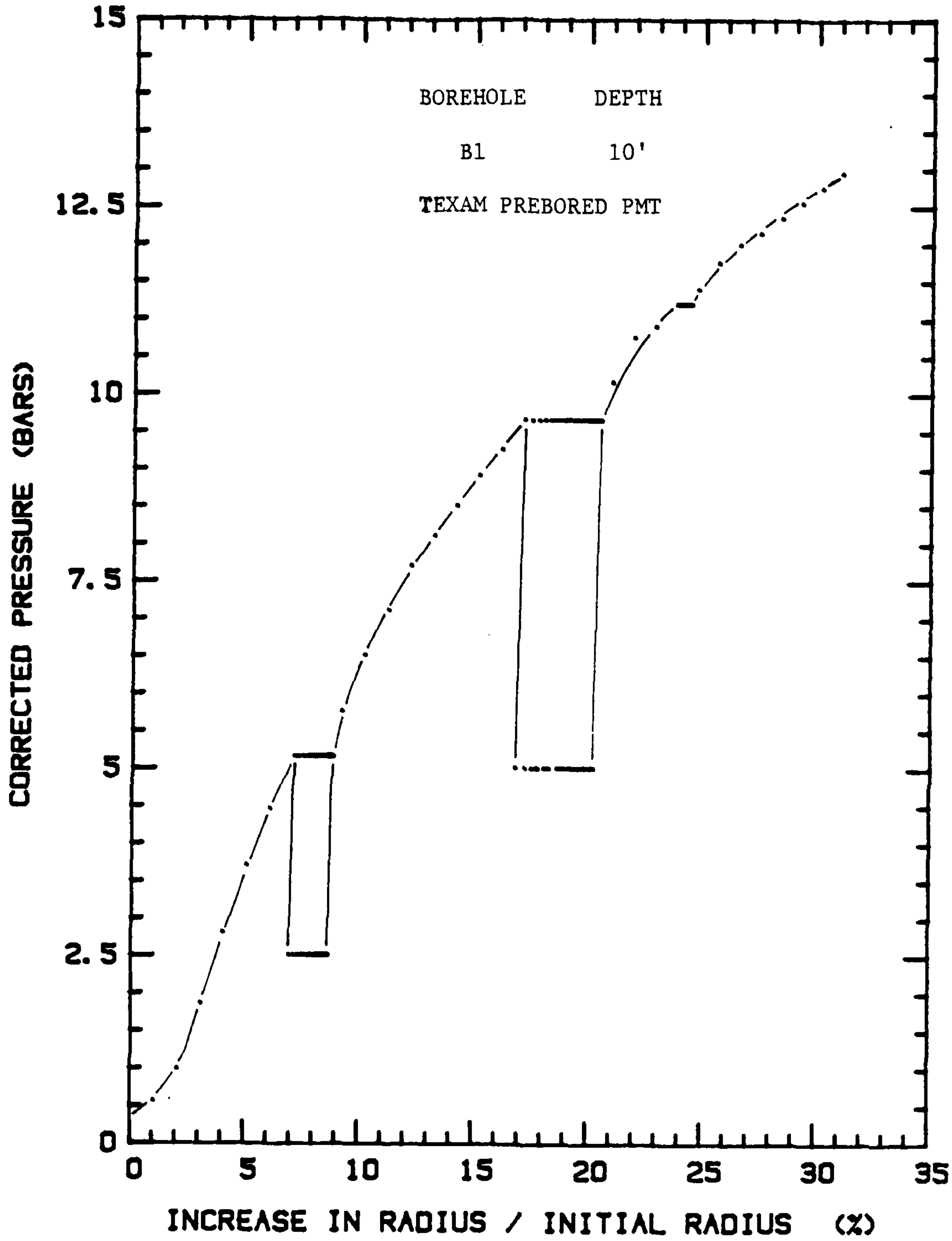
BOREHOLE DEPTH
D1 17'
DRIVEN PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
5
10
15
20
25
30

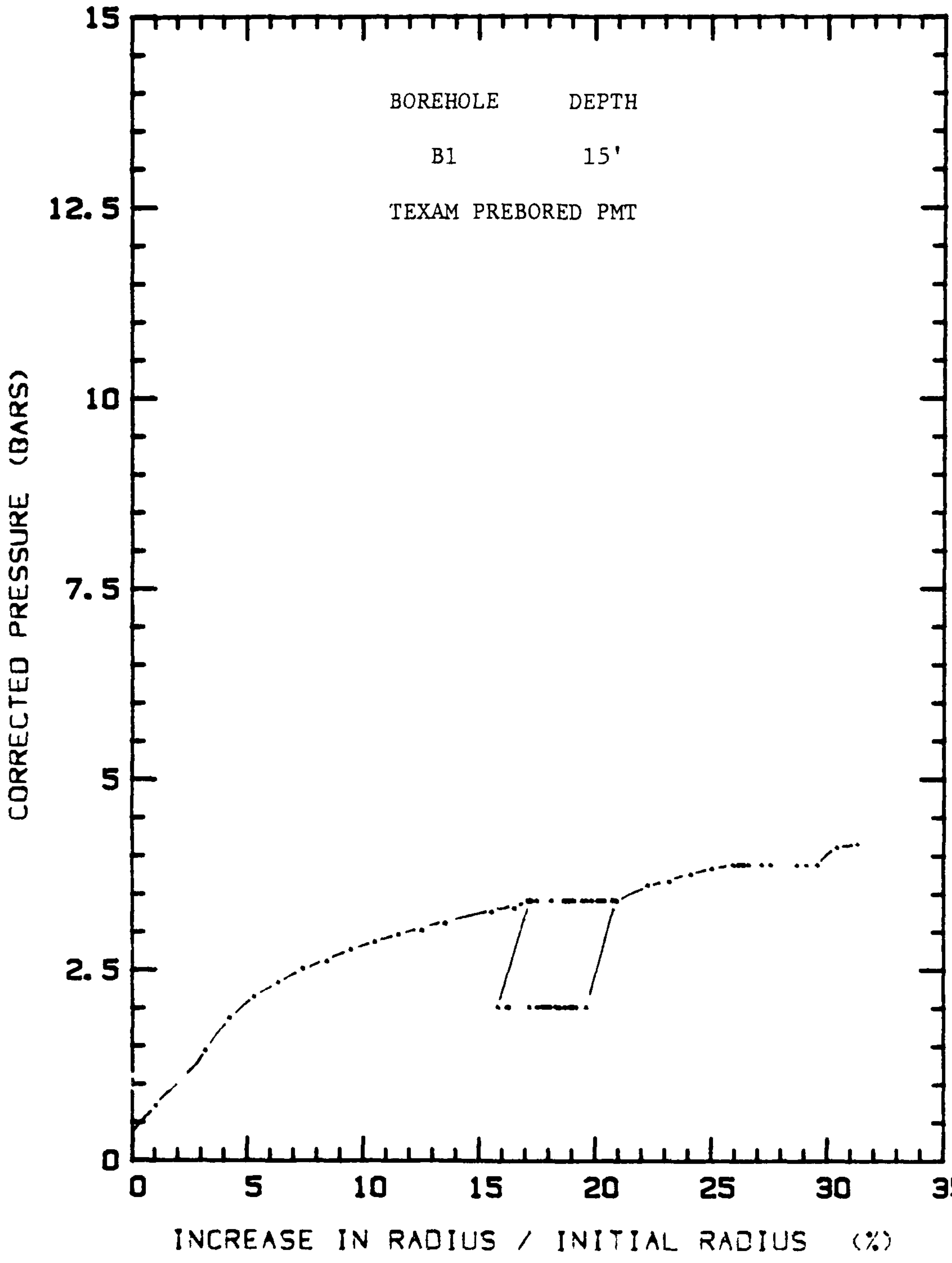


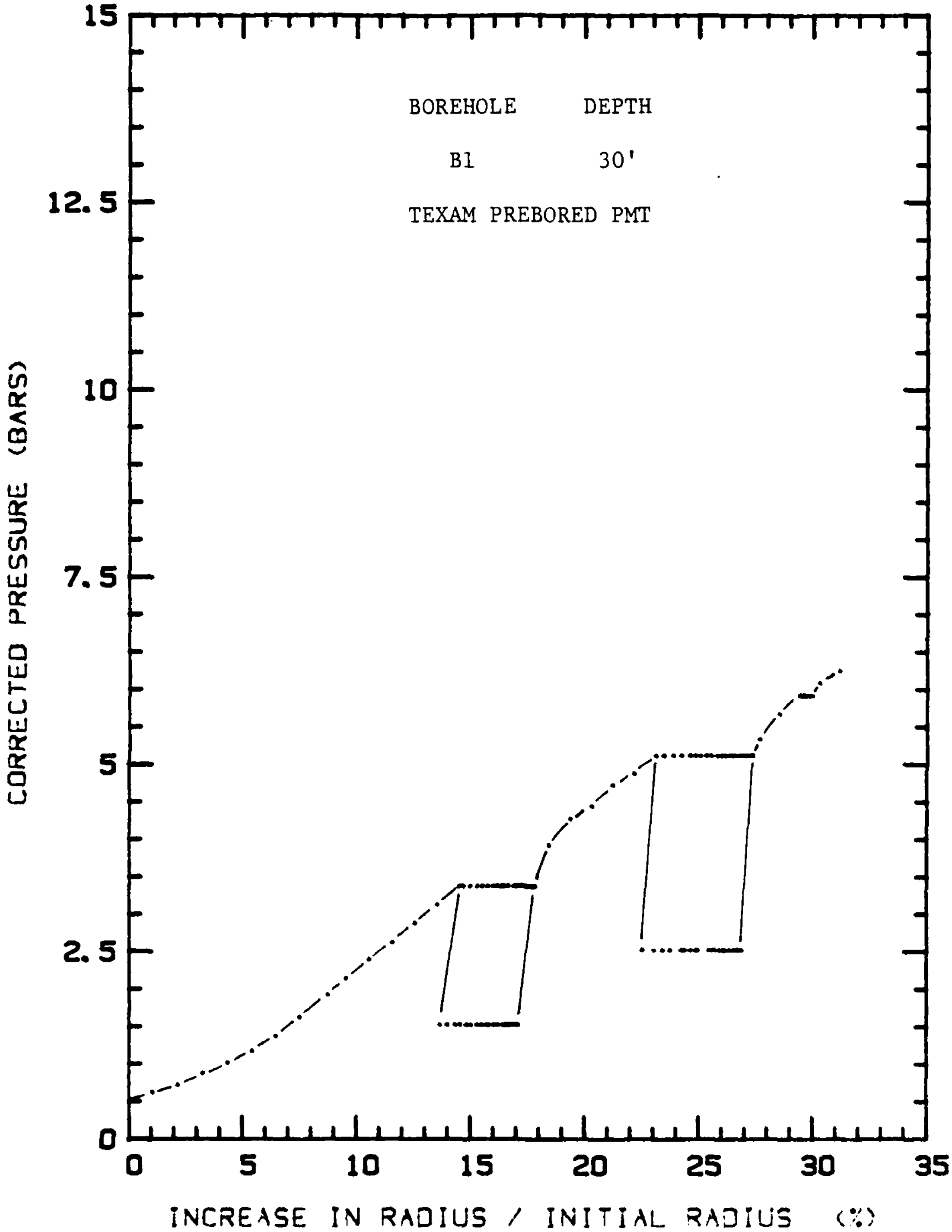
BOREHOLE DEPTH
B2 2'
TEXAM PREBORED PMT
15
12.5
10
7.5
5
2.5
0
0
5
10
15
20
25
30
35
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)

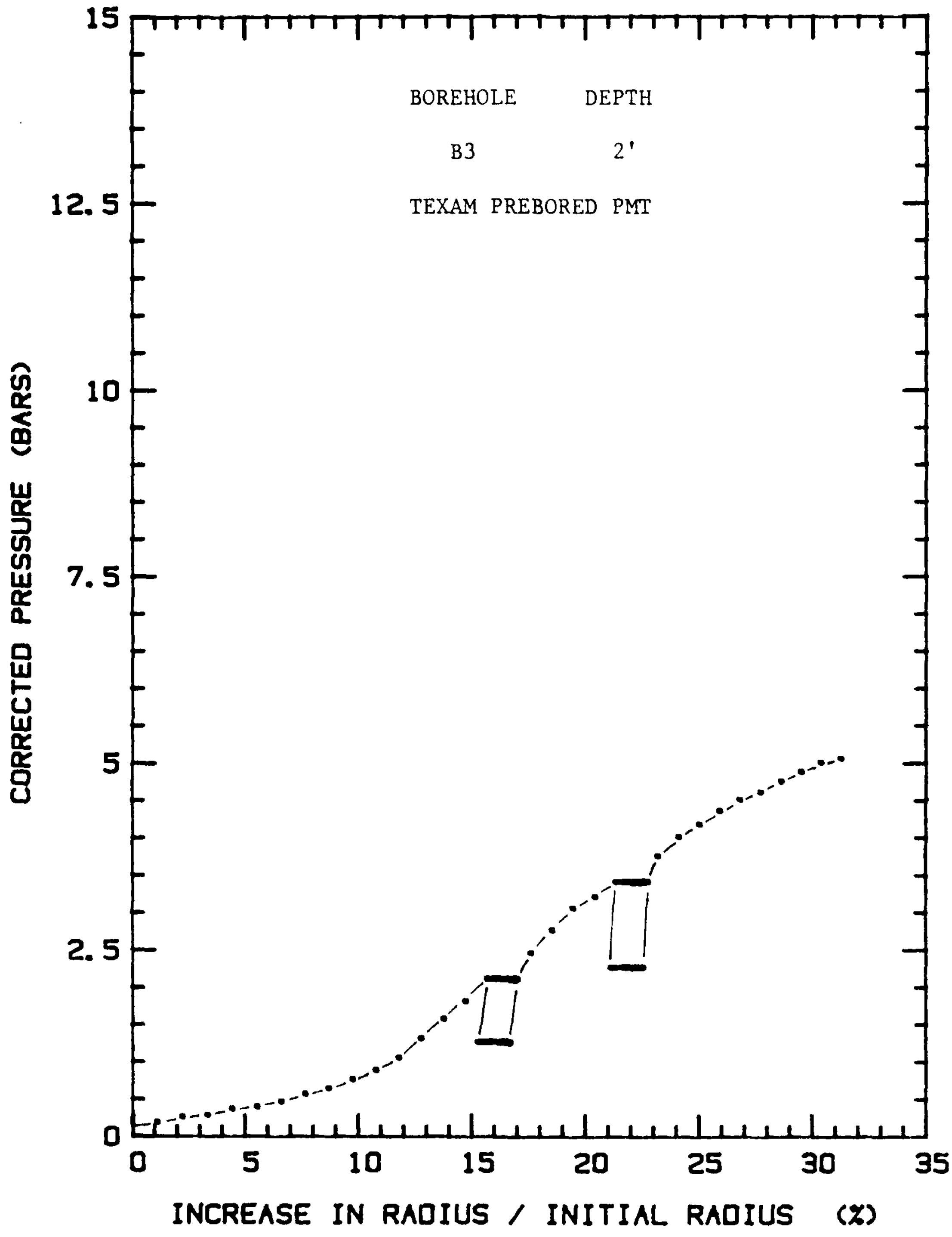


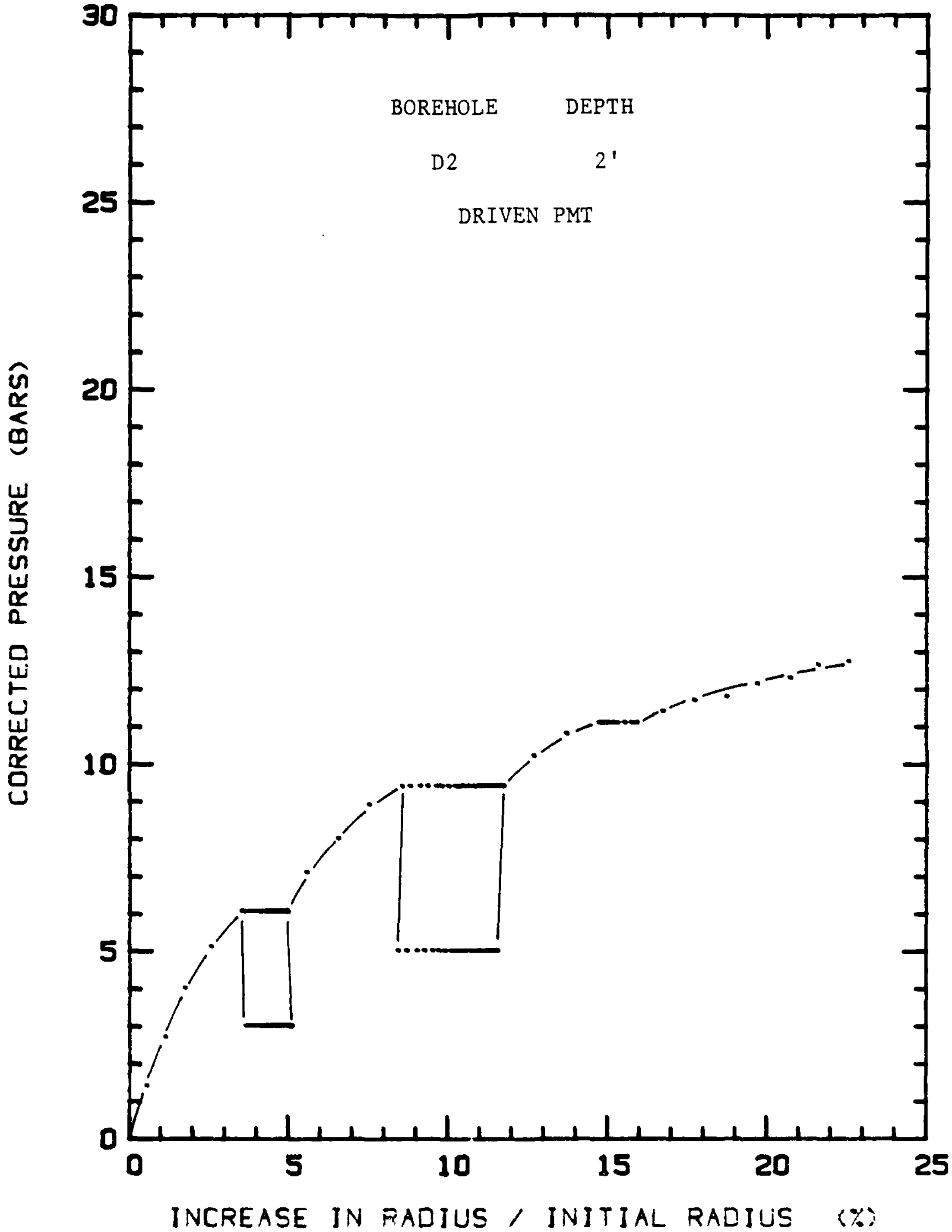
15
12.5
10
7.5
5
2.5
0
BOREHOLE DEPTH
B1 7'
TEXAM PREBORED PMT
CORRECTED PRESSURE (BARS)
0
5
10
15
20
25
30
35
INCREASE IN RADIUS / INITIAL RADIUS (%)


BOREHOLE DEPTH
B1 10'
TEXAM PREBORED PMT
CORRECTED PRESSURE (BARS)
0
2.5
5
7.5
10
12.5
15
0
5
10
15
20
25
30
35
INCREASE IN RADIUS / INITIAL RADIUS (%)


BOREHOLE DEPTH
B1 15'
TEXAM PREBORED PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
2.5
5
7.5
10
12.5
15
0
5
10
15
20
25
30
35


BOREHOLE DEPTH
B1 30'
TEXAM PREBORED PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
2.5
5
7.5
10
12.5
15
0
5
10
15
20
25
30
35

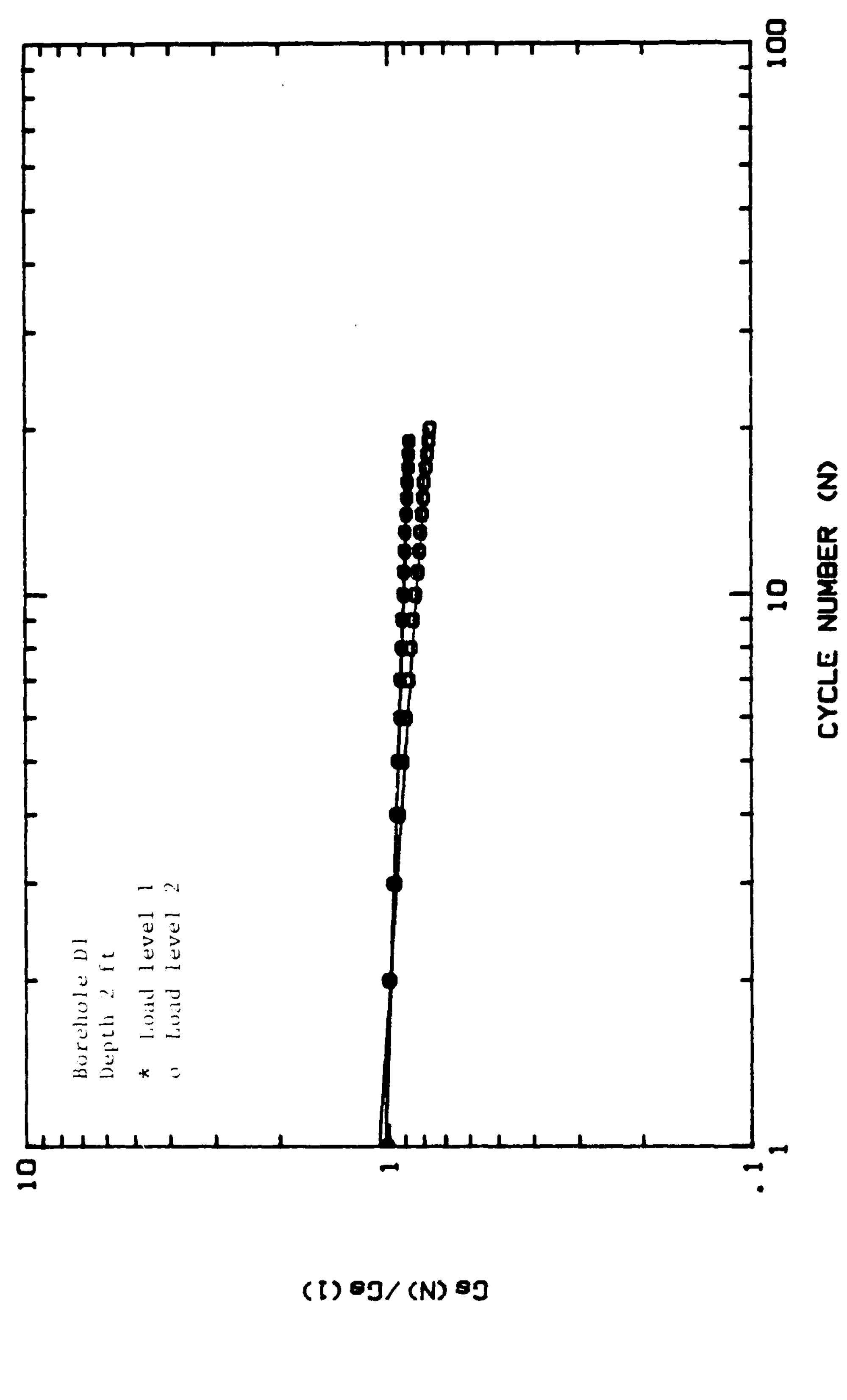

BOREHOLE DEPTH
B3 2'
TEXAM PREBORED PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
2.5
5
7.5
10
12.5
15
0
5
10
15
20
25
30
35

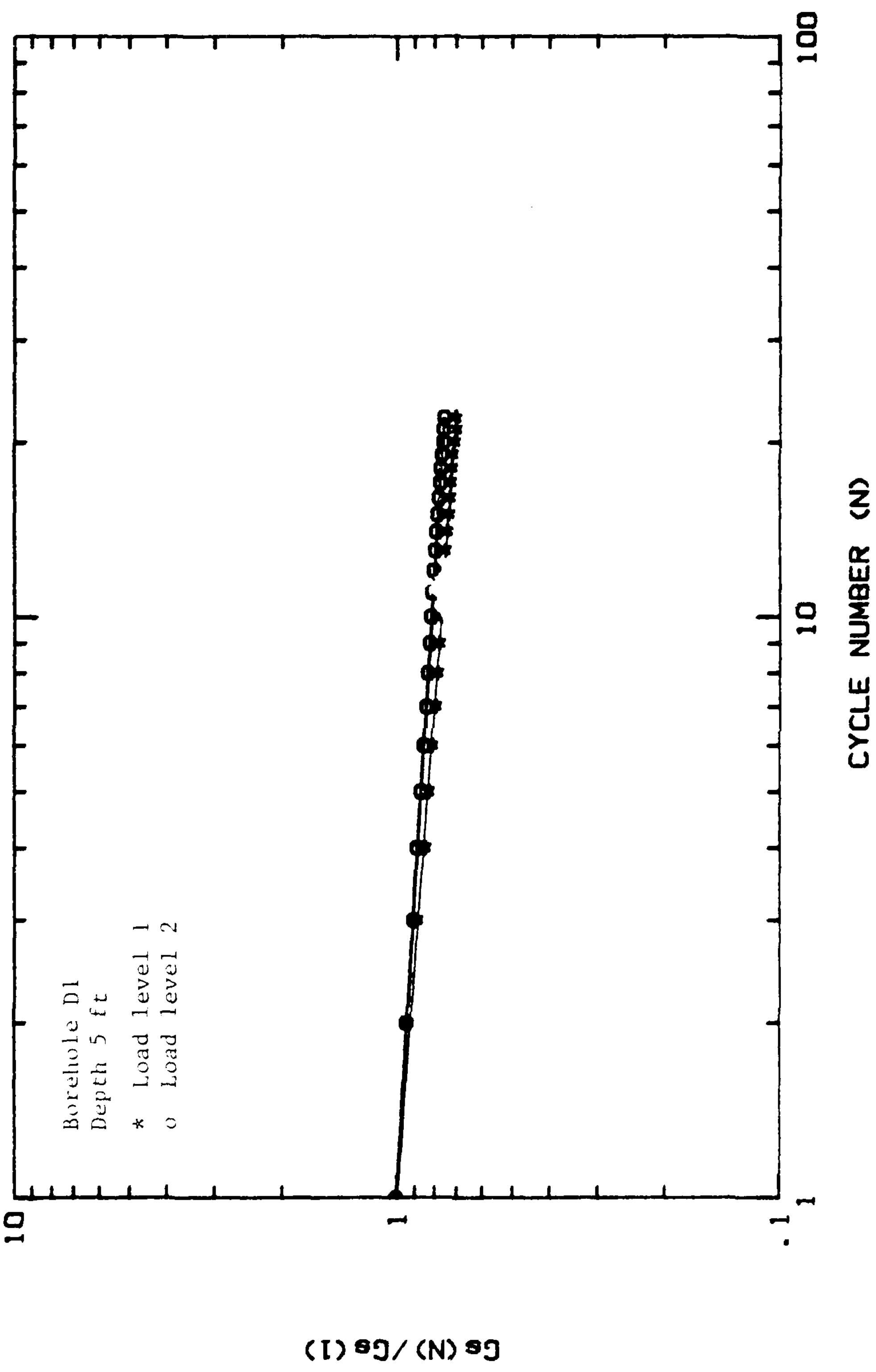


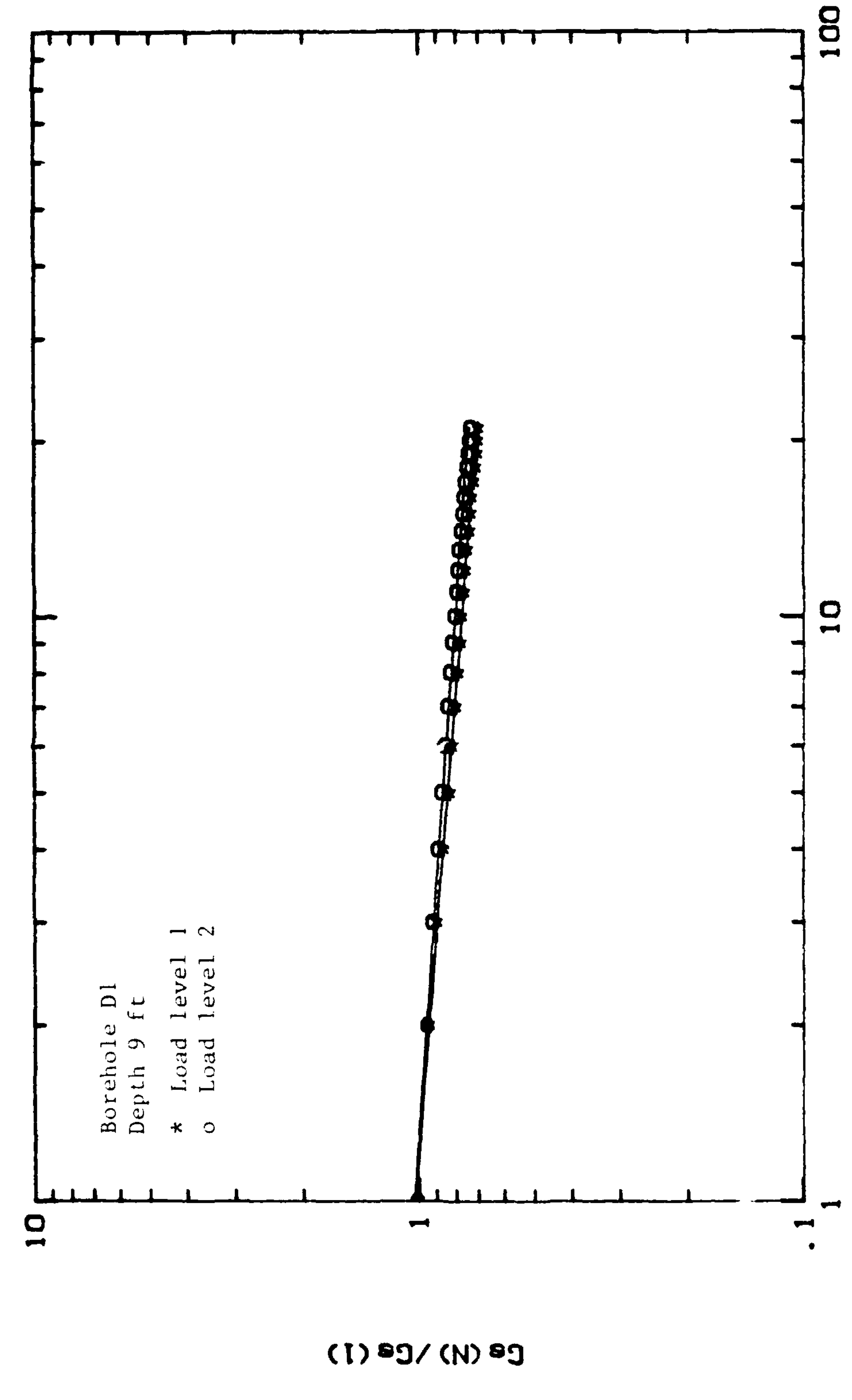
BOREHOLE DEPTH
D2 2'
DRIVEN PMT
CORRECTED PRESSURE (BARS)
INCREASE IN RADIUS / INITIAL RADIUS (%)
0
5
10
15
20
25
30

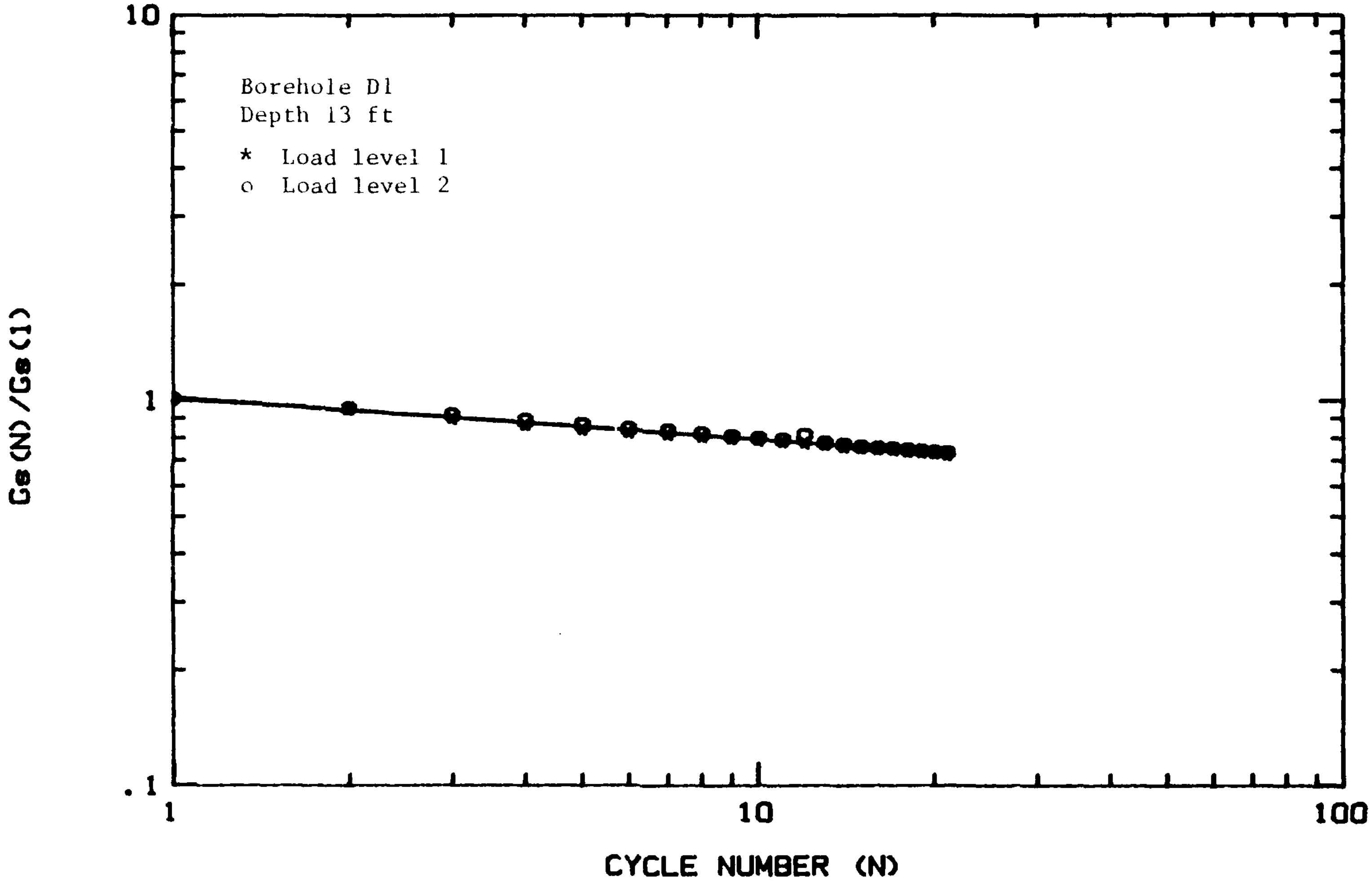
# APPENDIX C

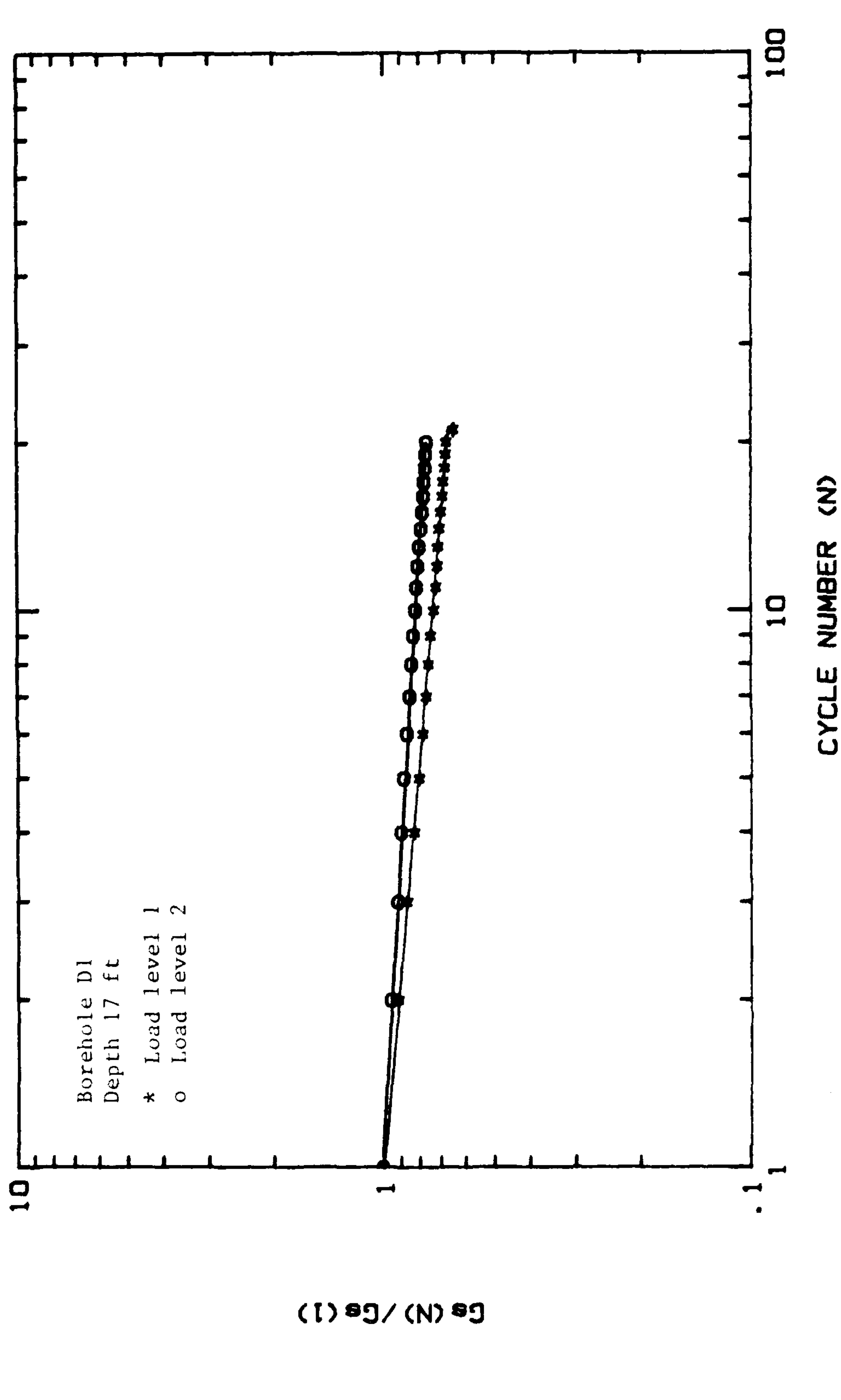
## CYCLIC DEGRADATION OF THE PMT SECANT SHEAR MODULUS

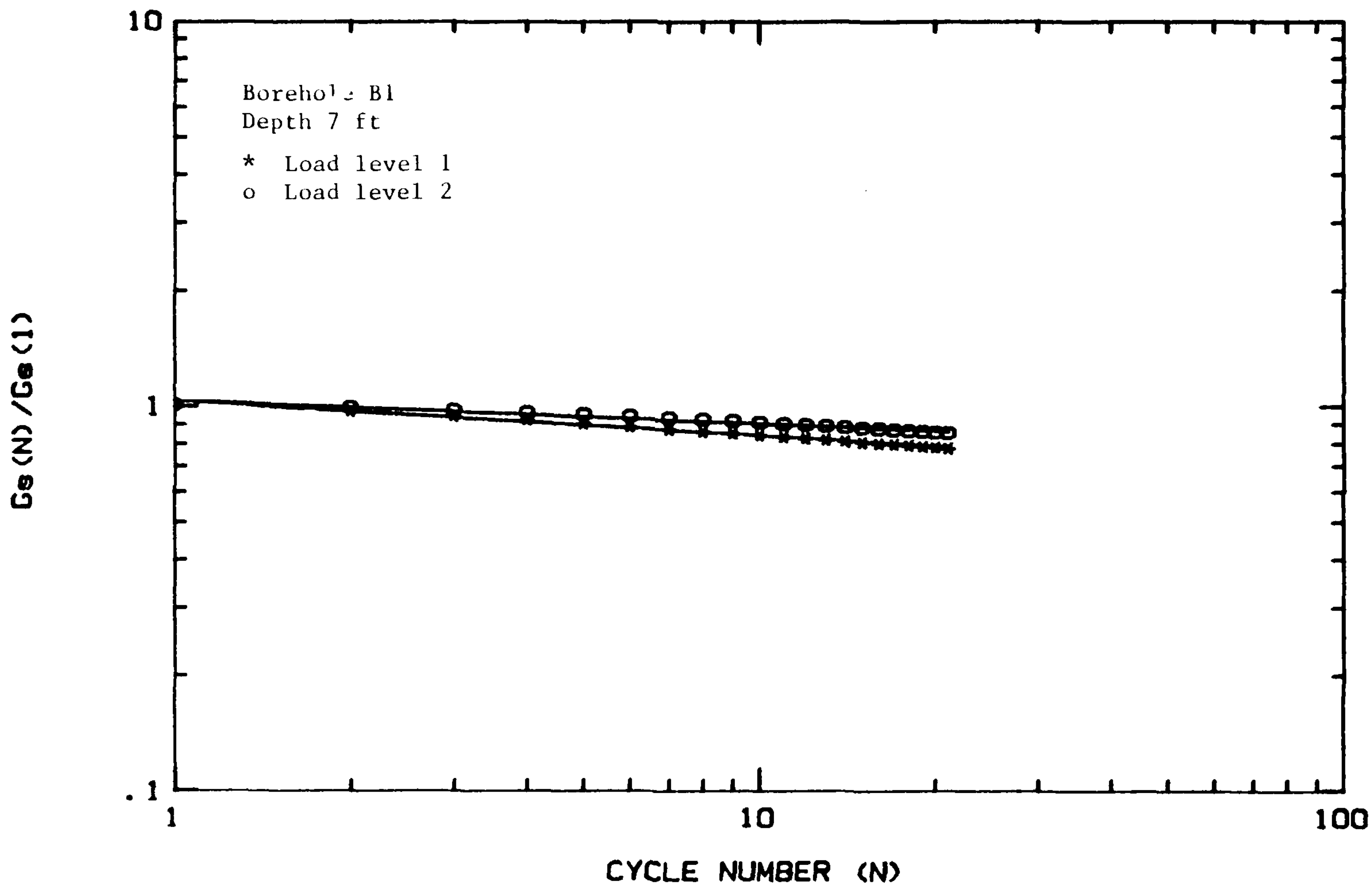

Borehole D1
Depth 2 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
Gs (N)/Gs (1)
1
10
100
.1
1
10

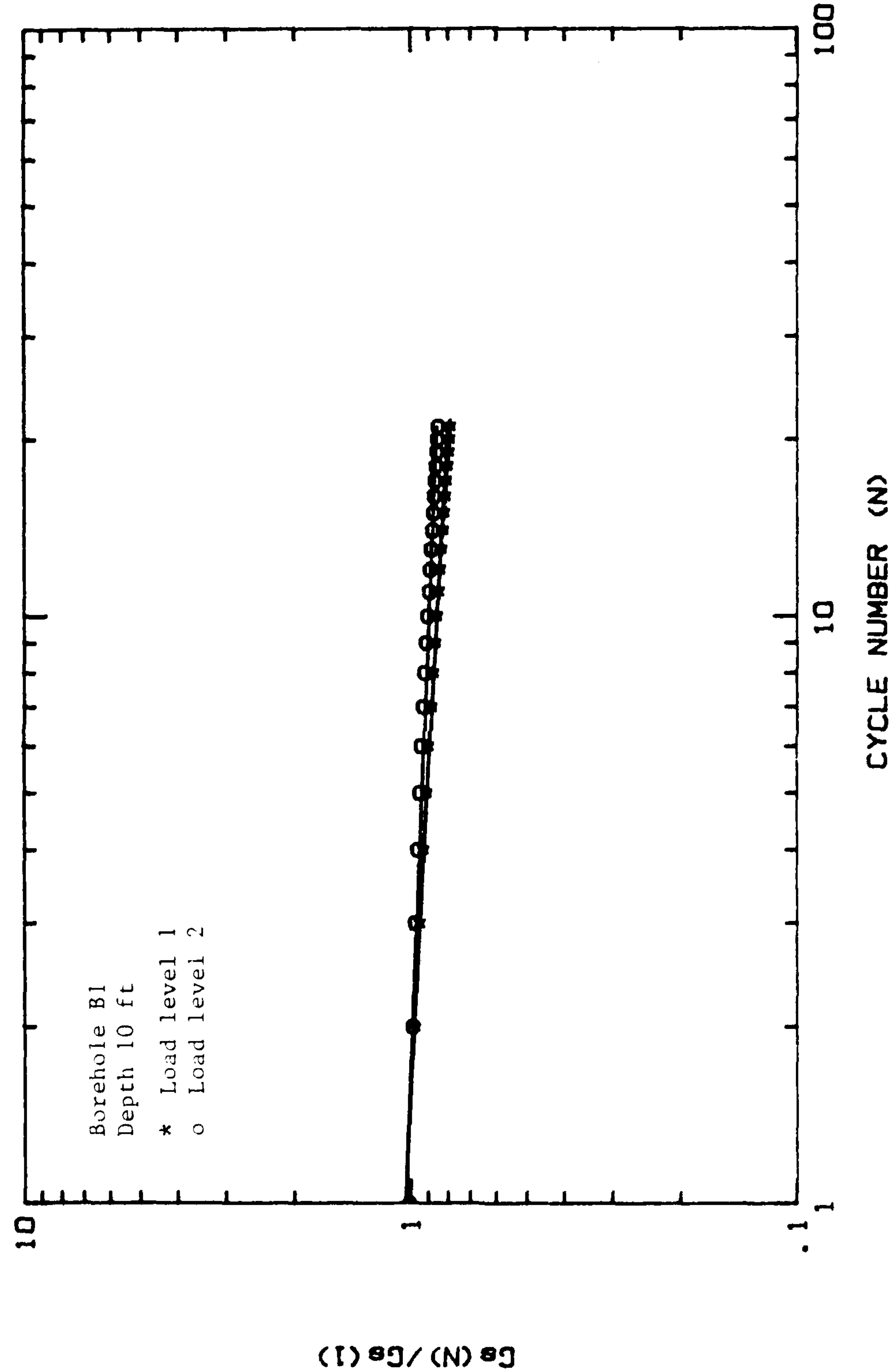

Borehole D1
Depth 5 ft
* Load level 1
o Load level 2
Gs (N)/Gs (1)
10
1
.1
1
10
100
CYCLE NUMBER (N)

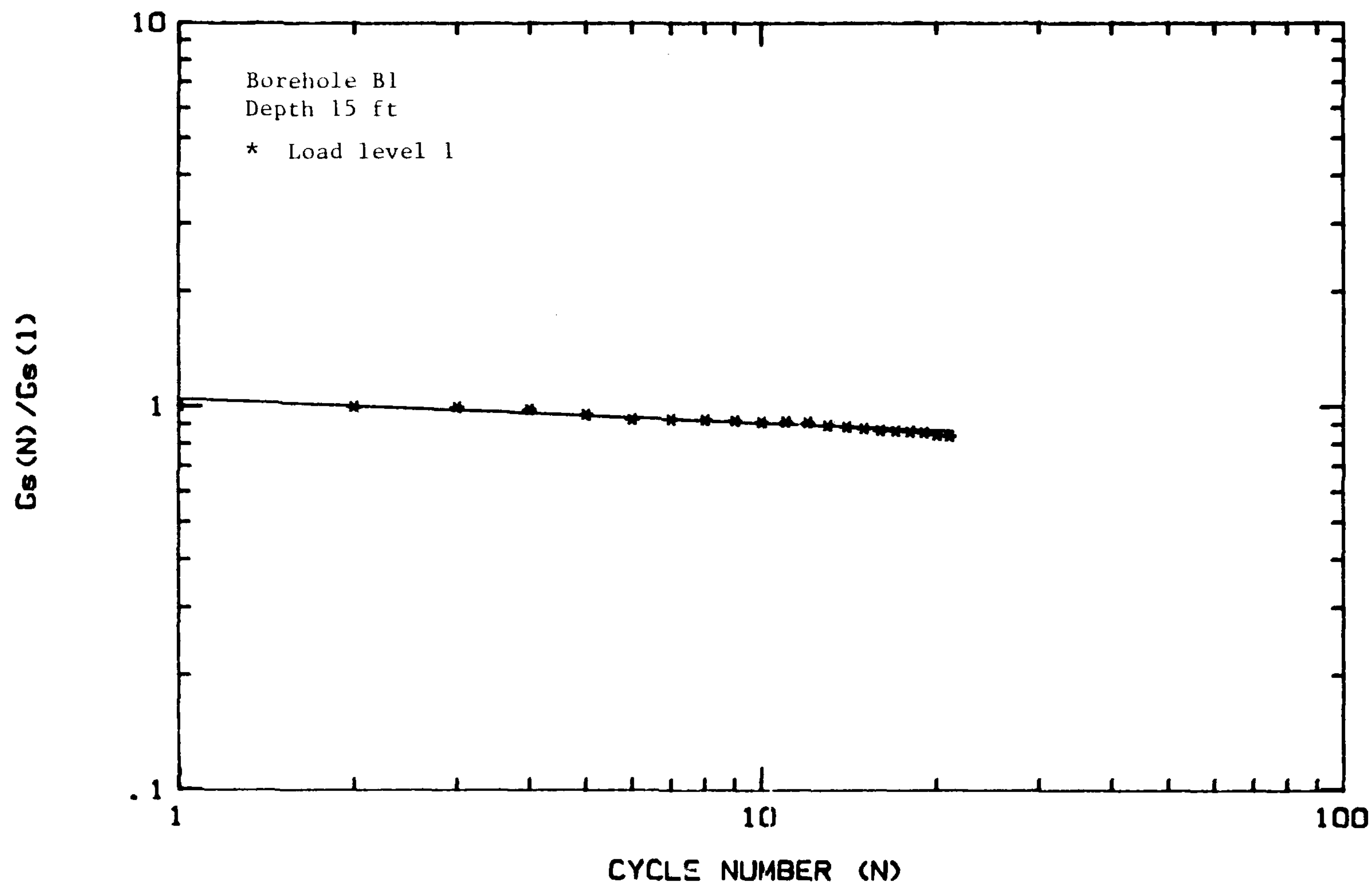

Borehole D1
Depth 9 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
Gs (N) /Gs (1)
10
1
.1
1
10
100

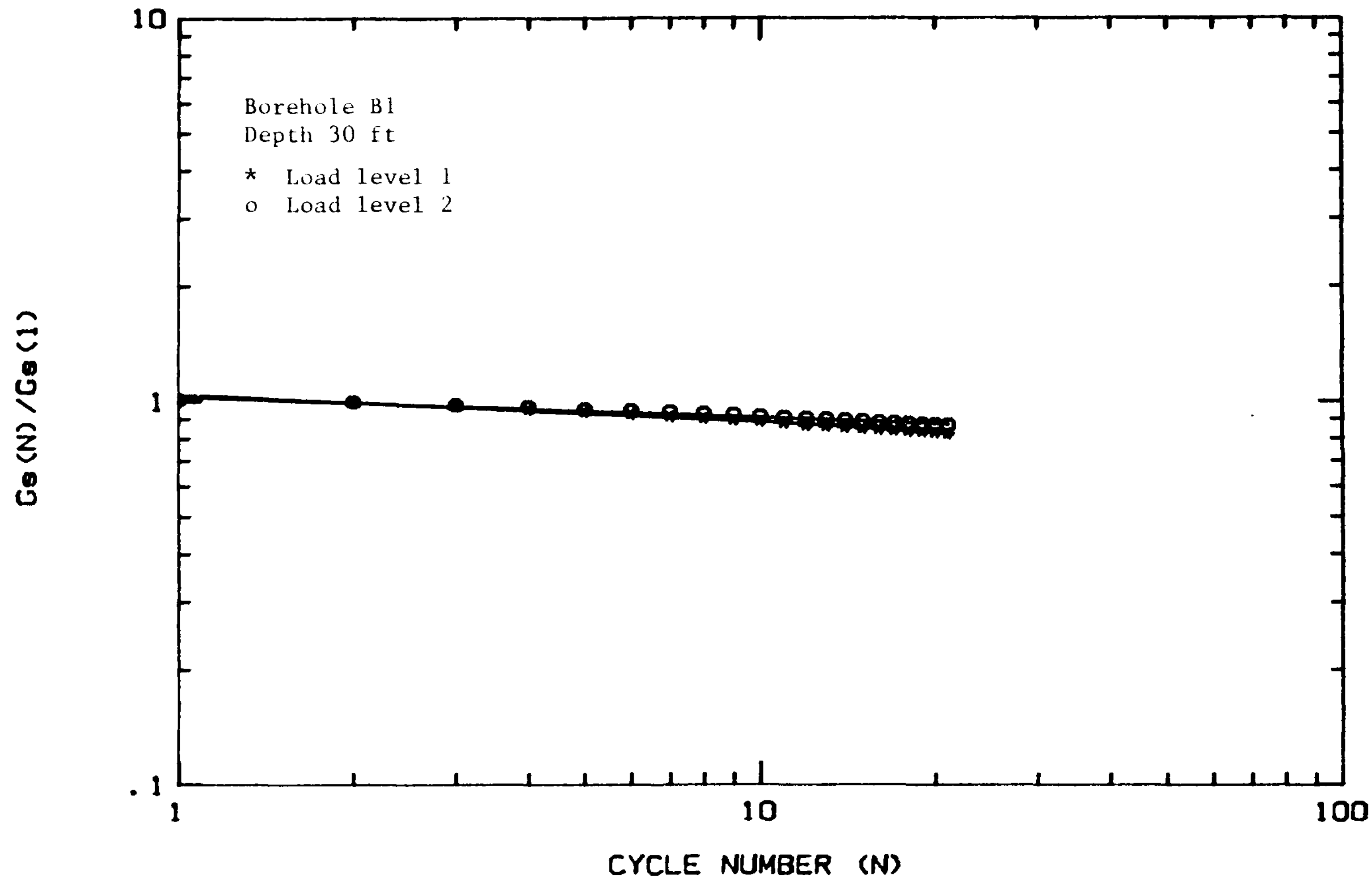

Borehole D1
Depth 13 ft
* Load level 1
o Load level 2
Gs (N) /Gs (1)
10
1
.1
1
10
100
CYCLE NUMBER (N)


Borehole D1
Depth 17 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
Gs(N)/Gs(1)
10
1
.1
1
10
100

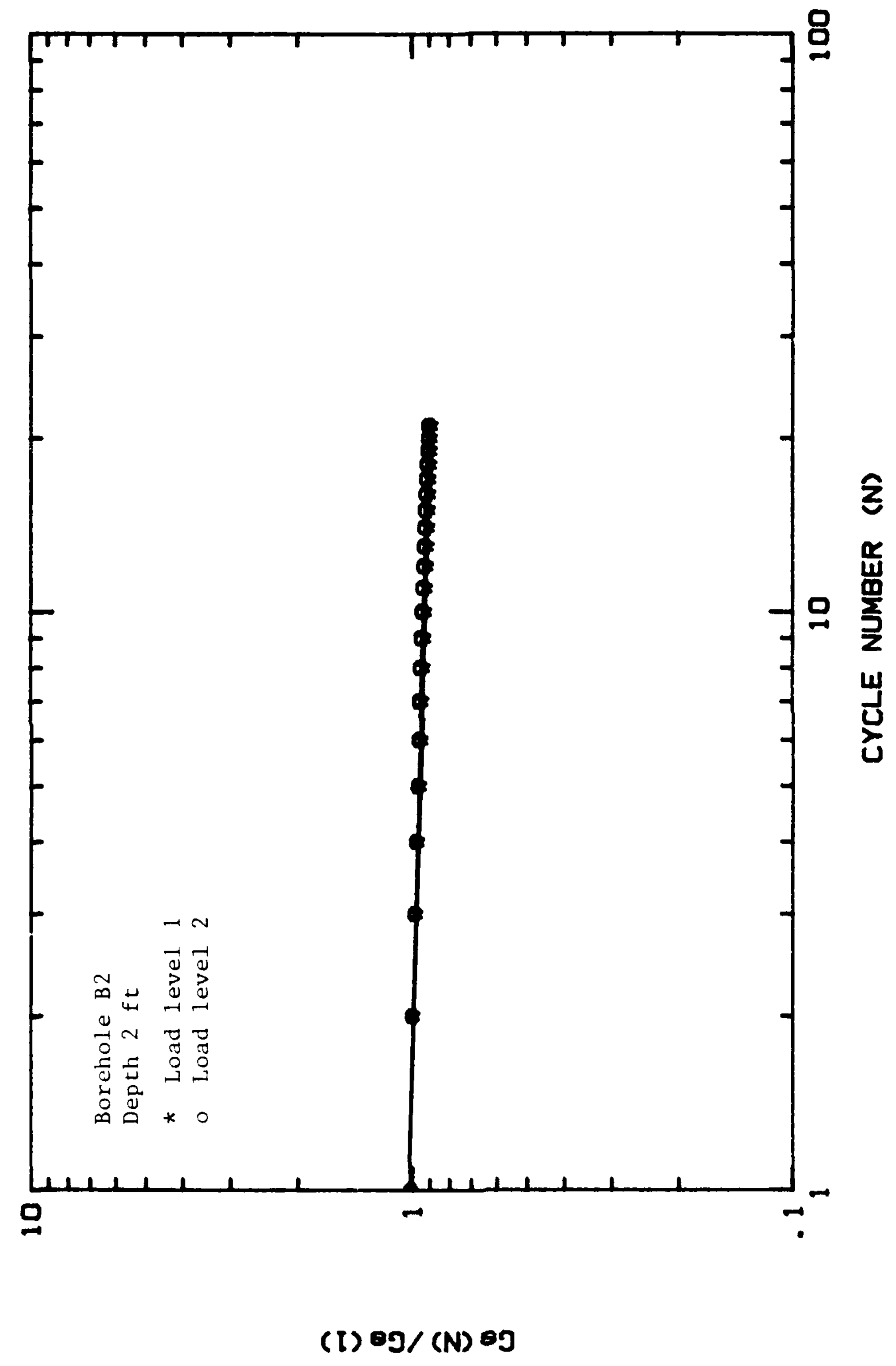

Borehole B1
Depth 7 ft
* Load level 1
o Load level 2
Gs (N) /Gs (1)
10
1
.1
1
10
100
CYCLE NUMBER (N)

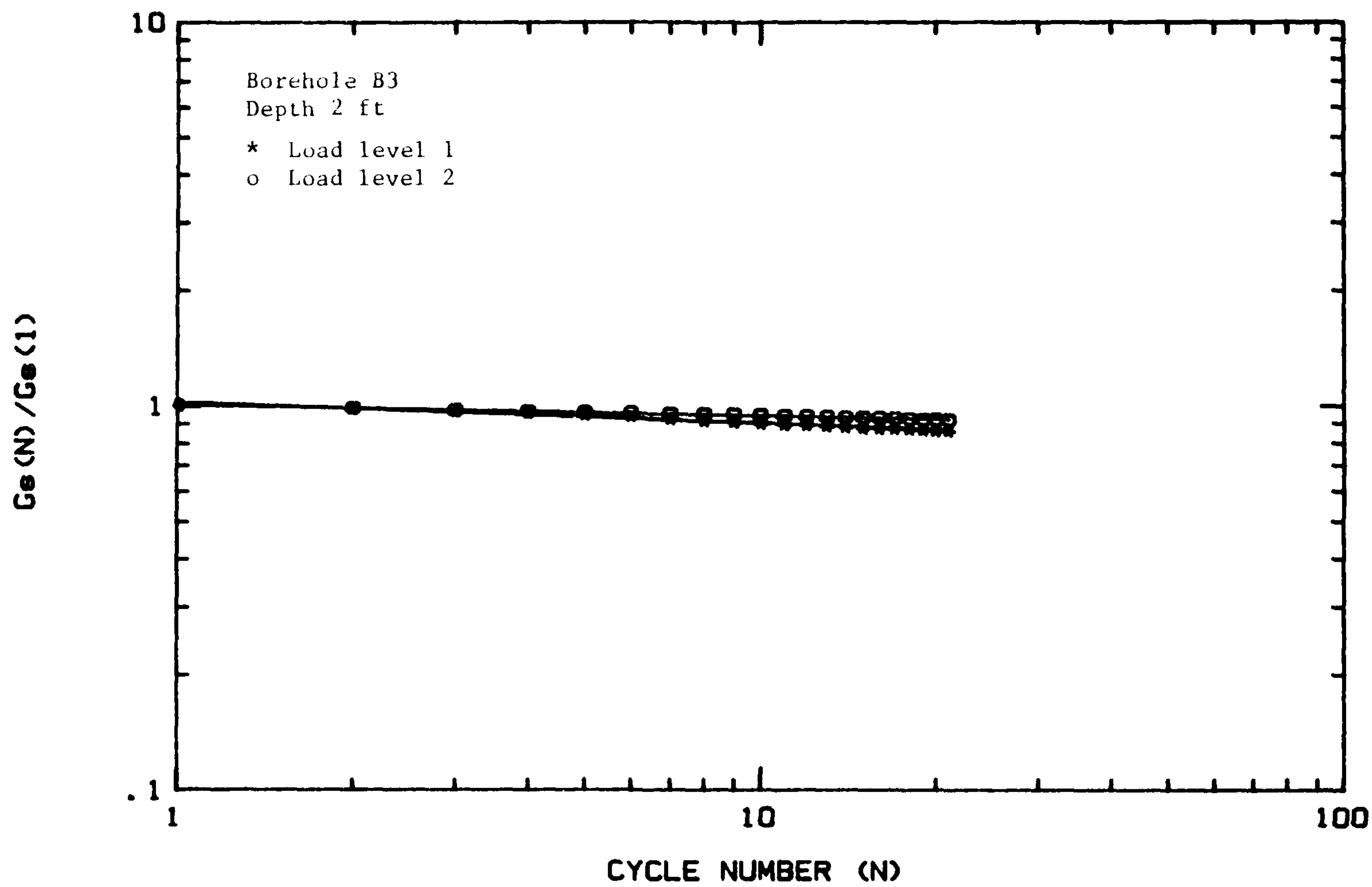

Borehole B1
Depth 10 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
Gs(N)/Gs(1)
10
1
.1
1
10
100

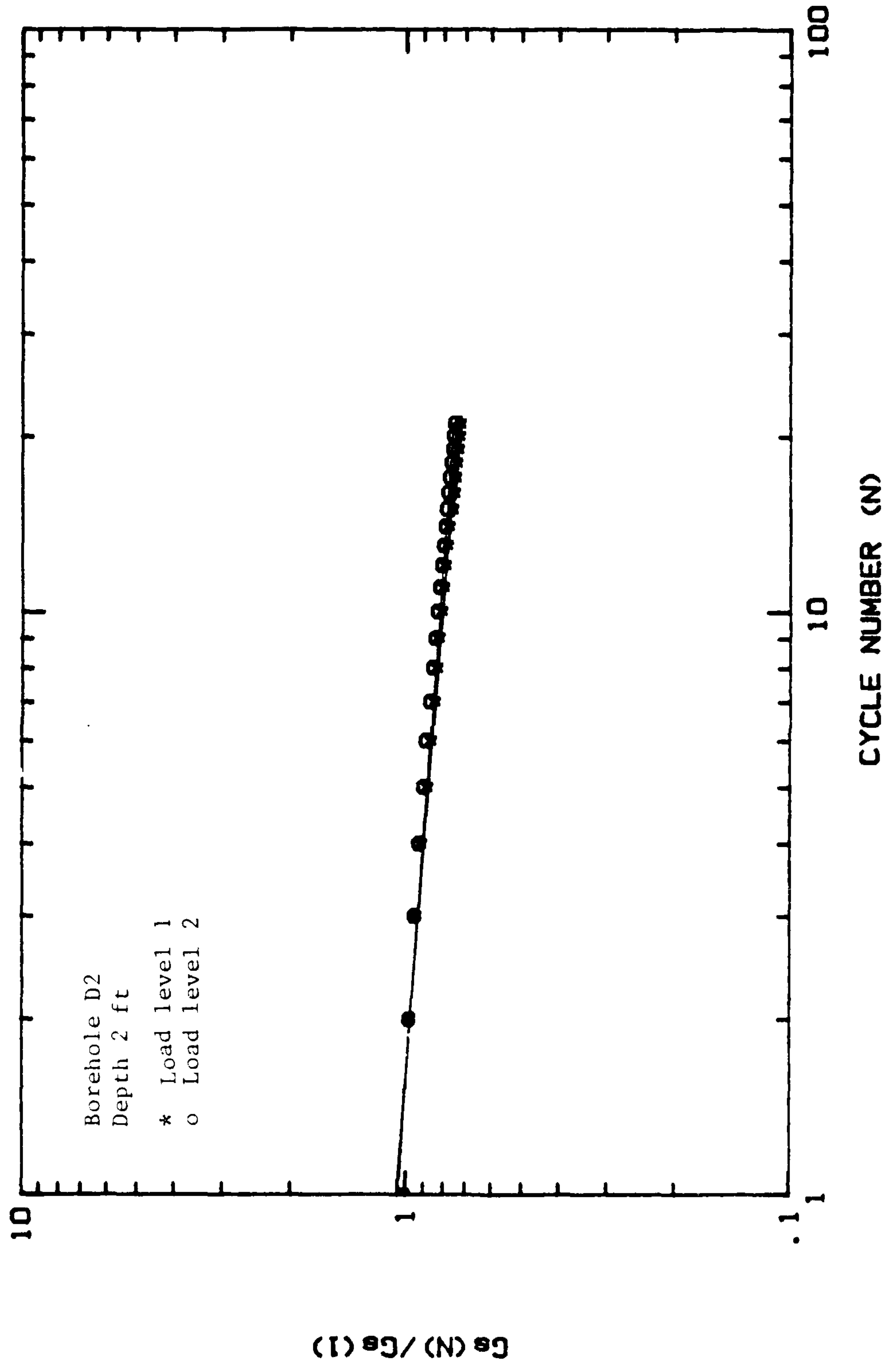

Borehole B1
Depth 15 ft
* Load level 1
10
1
.1
1
10
100
Gs(N)/Gs(1)
CYCLE NUMBER (N)



Borehole B1
Depth 30 ft
* Load level 1
o Load level 2
10
1
.1
1
10
100
Gs (N) /Gs (1)
CYCLE NUMBER (N)

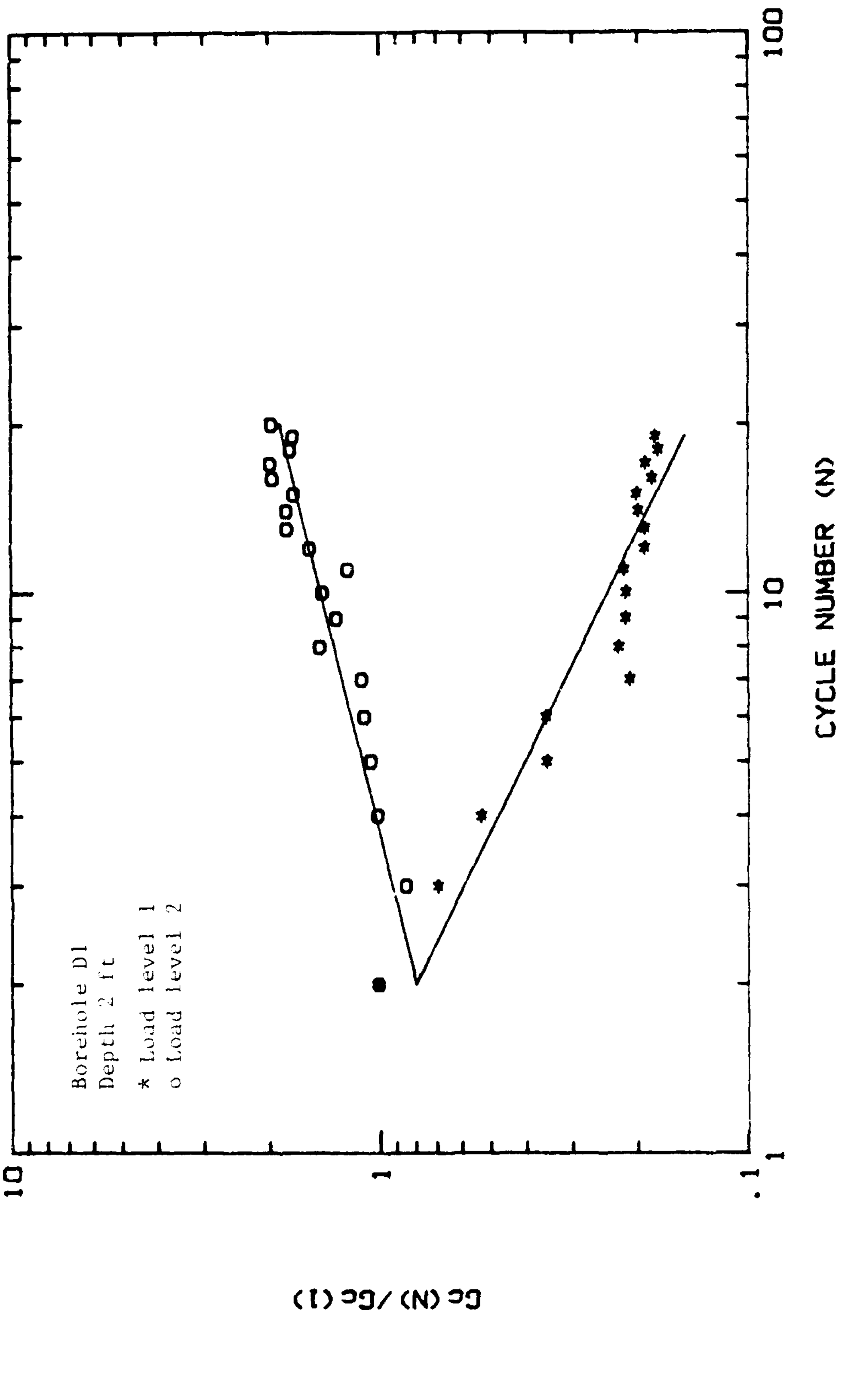

Borehole B2
Depth 2 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
1
10
100
10
1
.1


Borehole B3
Depth 2 ft
* Load level 1
o Load level 2
10
1
.1
1
10
100
Gs (N) /Gs (1)
CYCLE NUMBER (N)

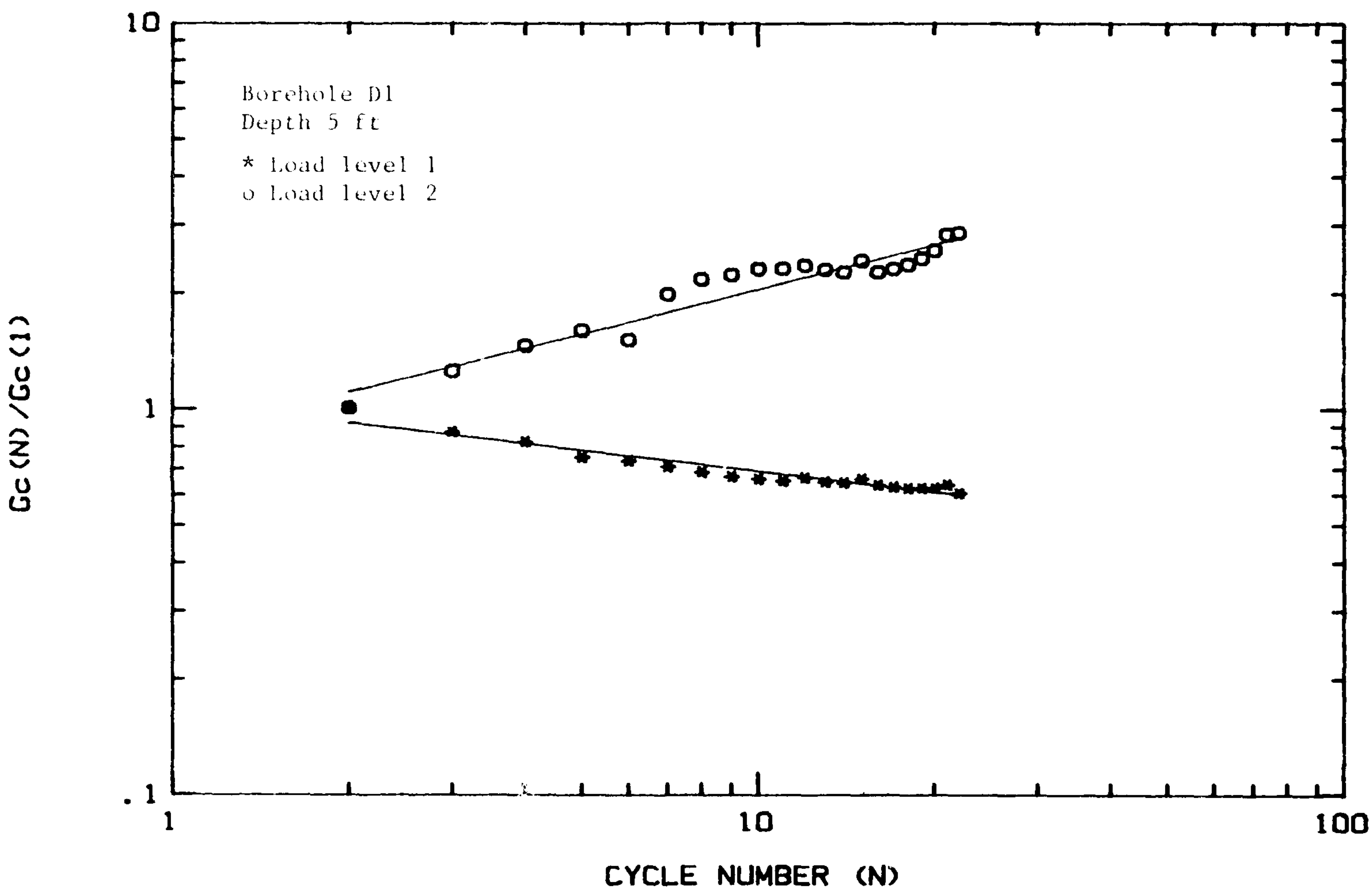

Borehole D2
Depth 2 ft
* Load level 1
o Load level 2
Gs (N) /Gs (1)
10
1
.1
1
10
100
CYCLE NUMBER (N)

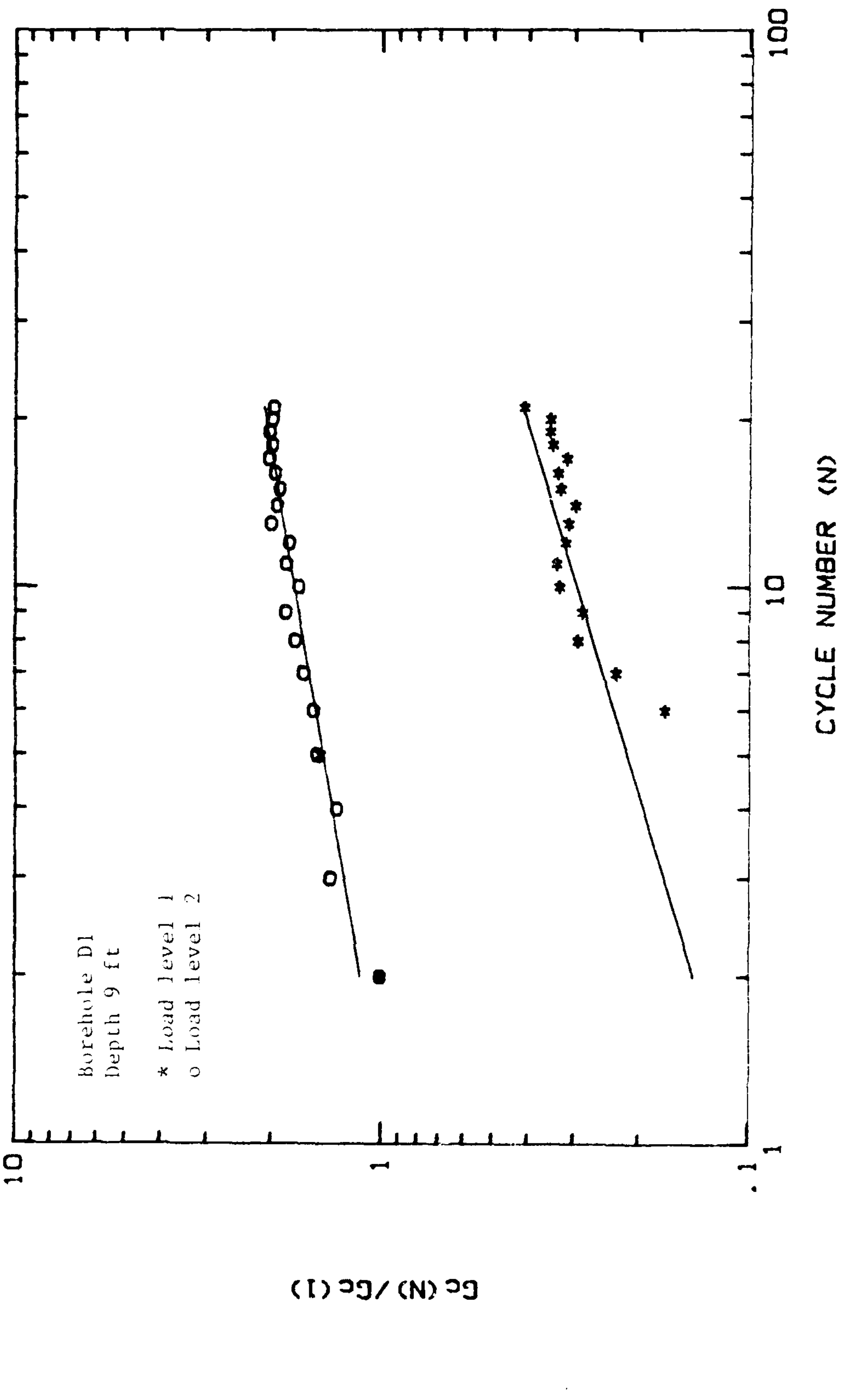
# APPENDIX D

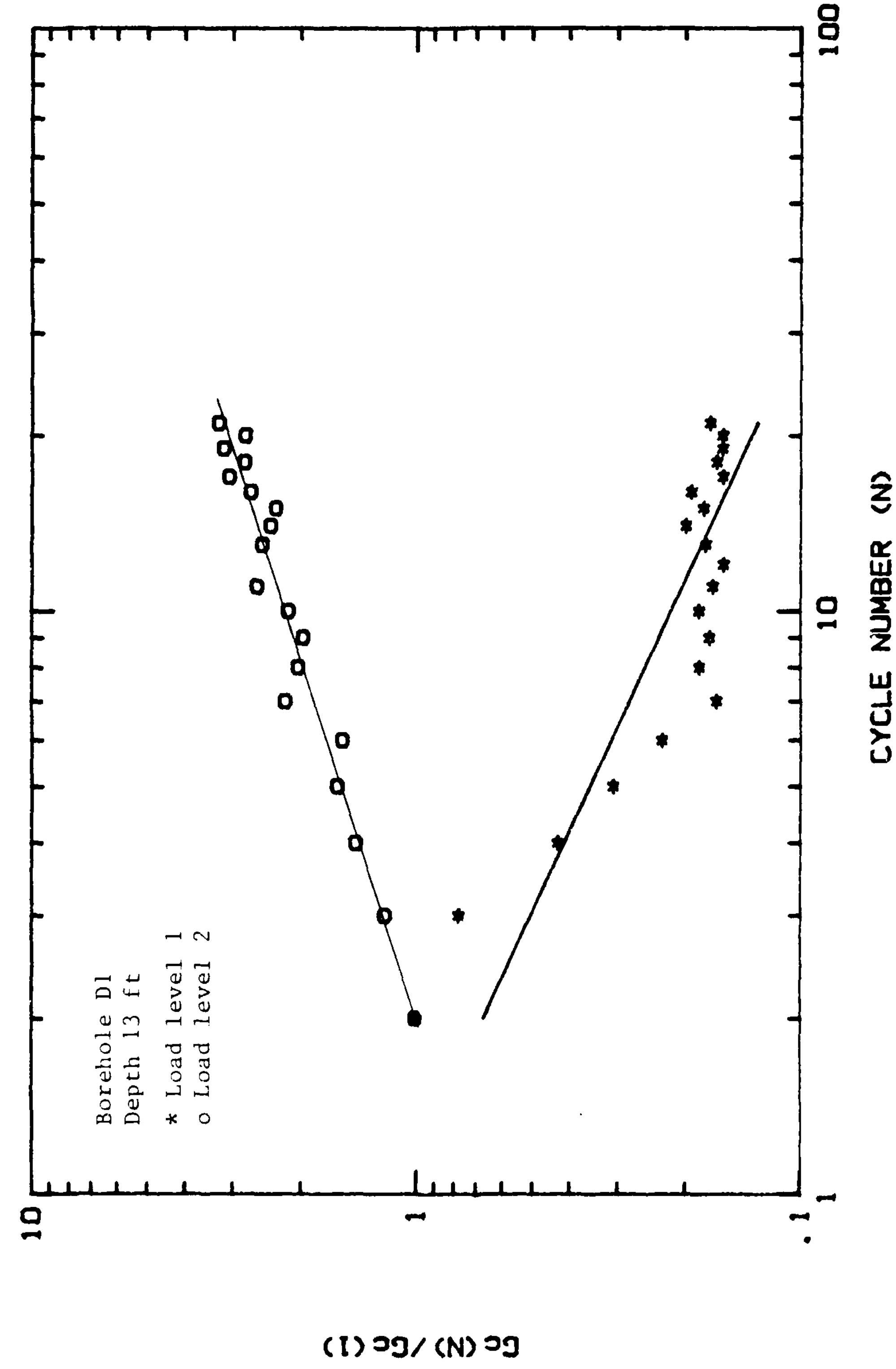
# CYCLIC DEGRADATION OF THE PMT CYCLIC SHEAR MODULUS

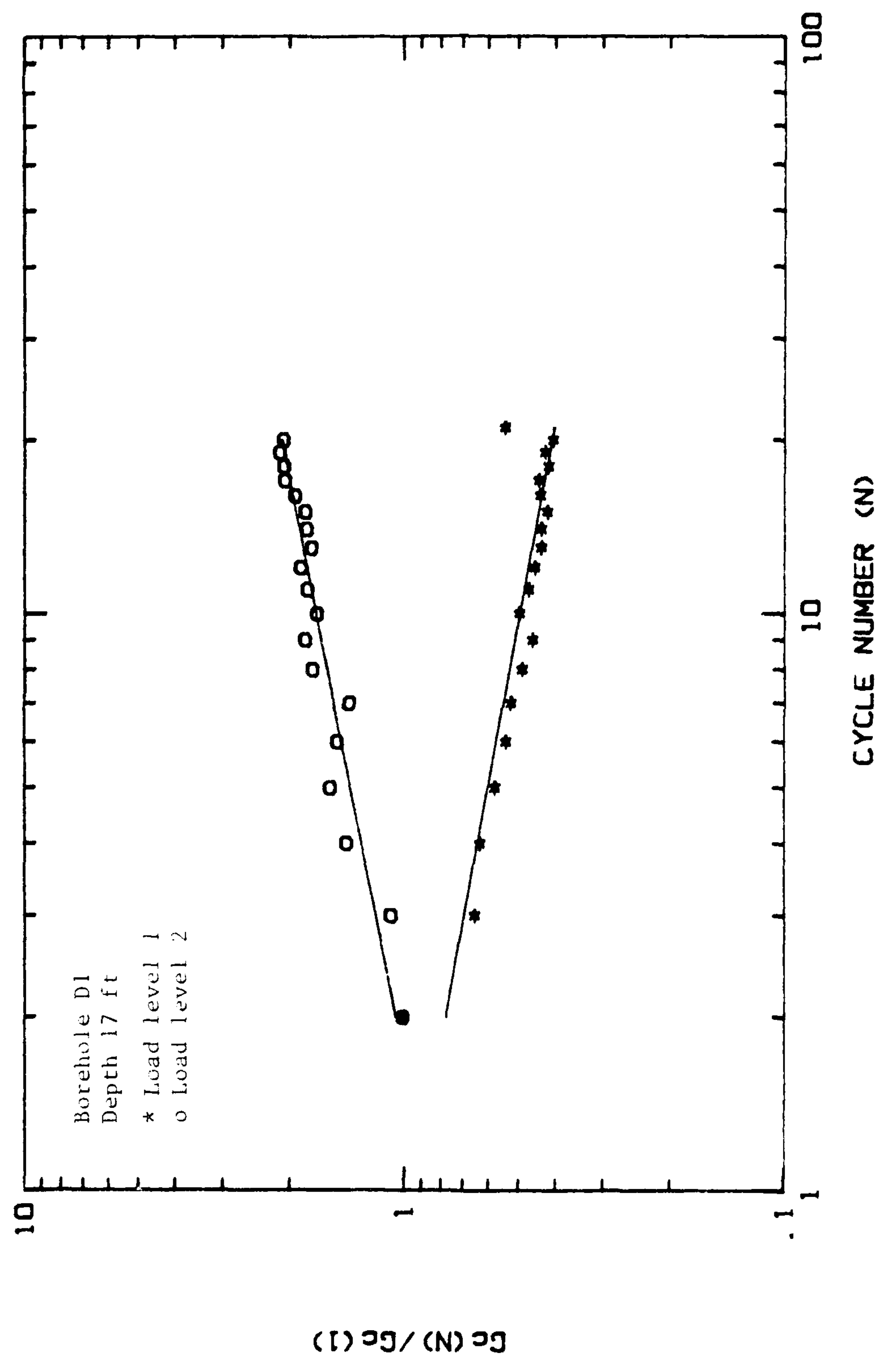


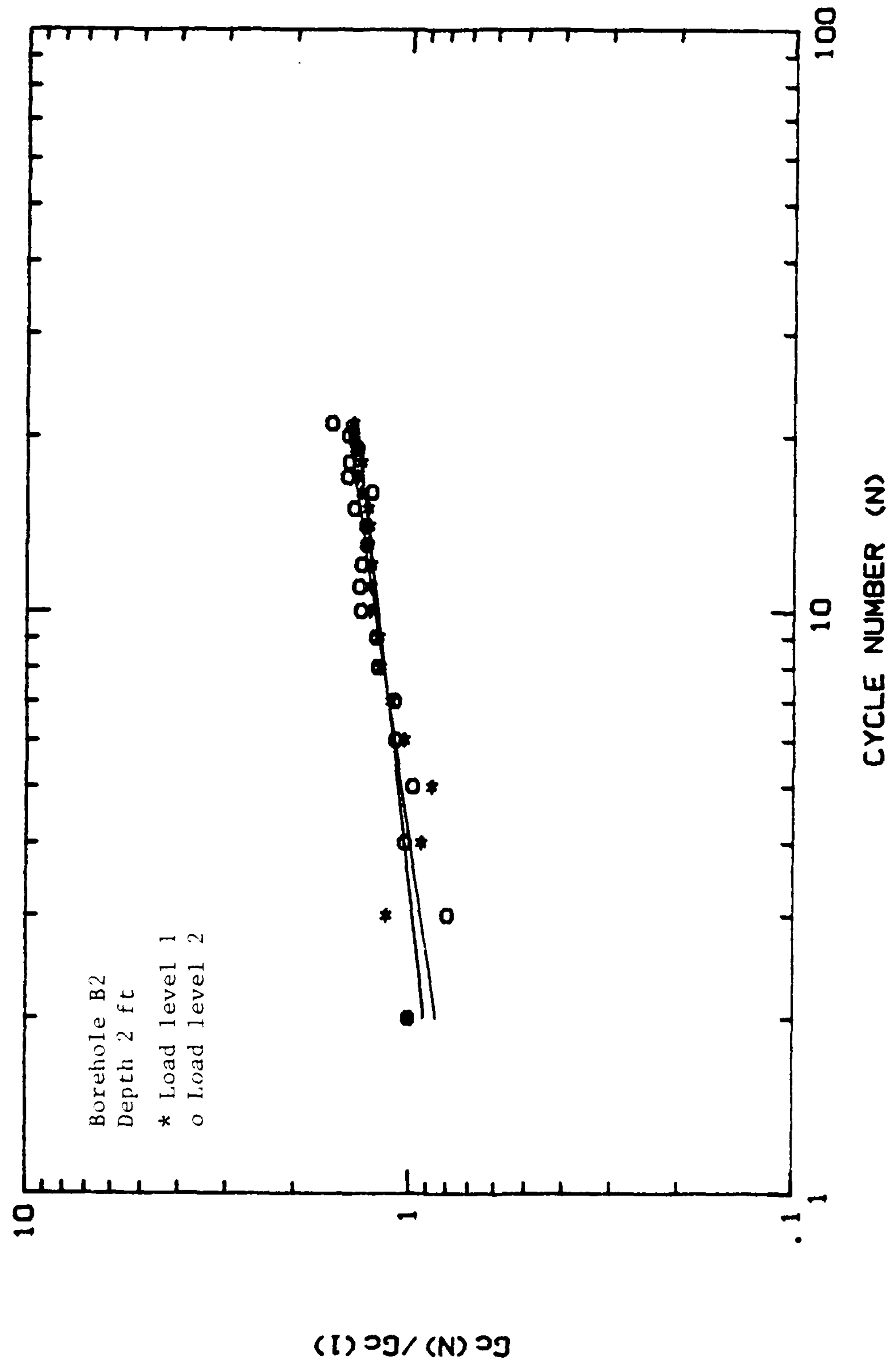
Borehole D1
Depth 2 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
Gc (N) /Gc (1)
10
1
.1
1
10
100

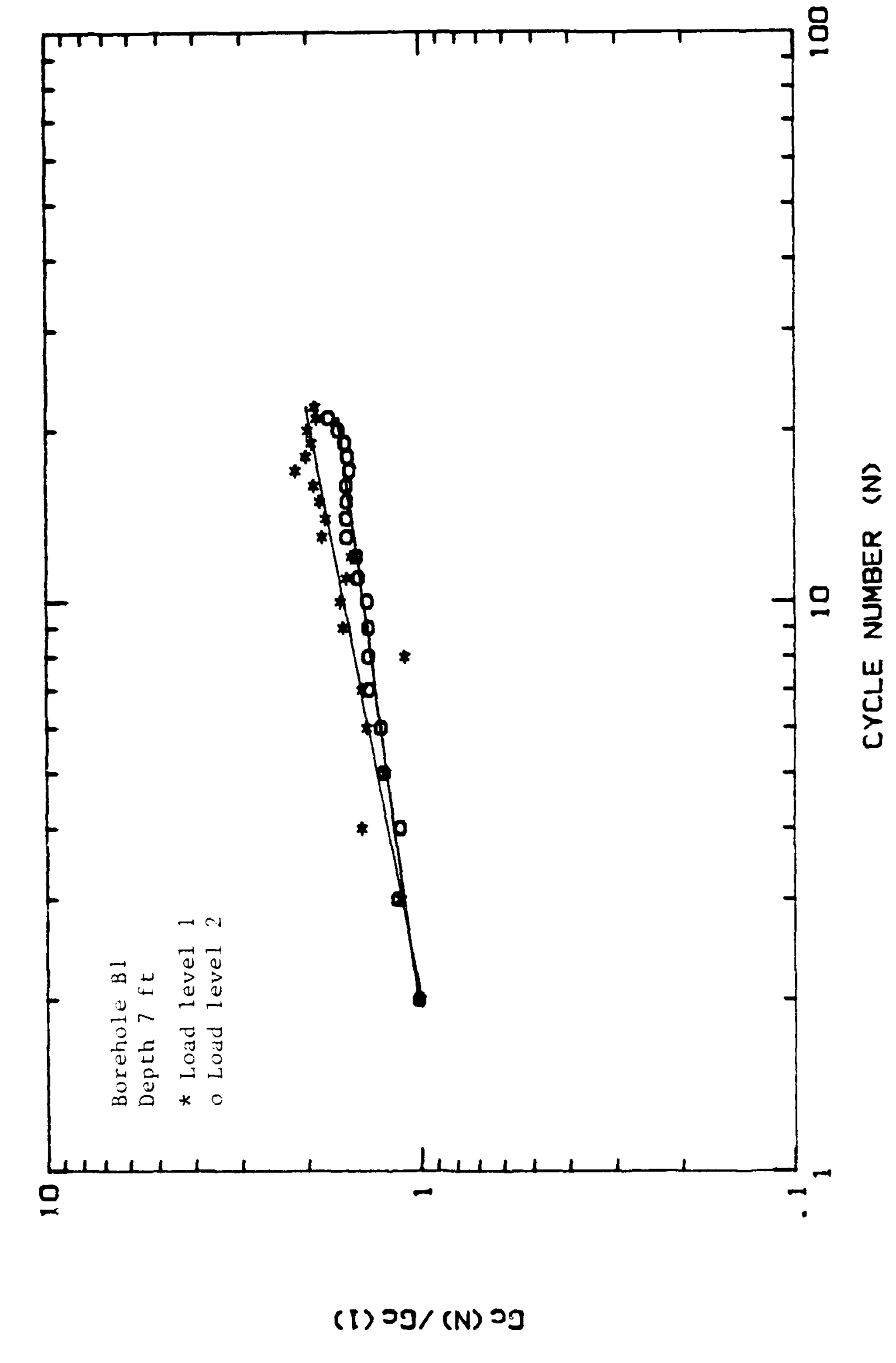

Borehole D1
Depth 5 ft
* Load level 1
o Load level 2
Gc (N) /Gc (1)
10
1
.1
1
10
100
CYCLE NUMBER (N)

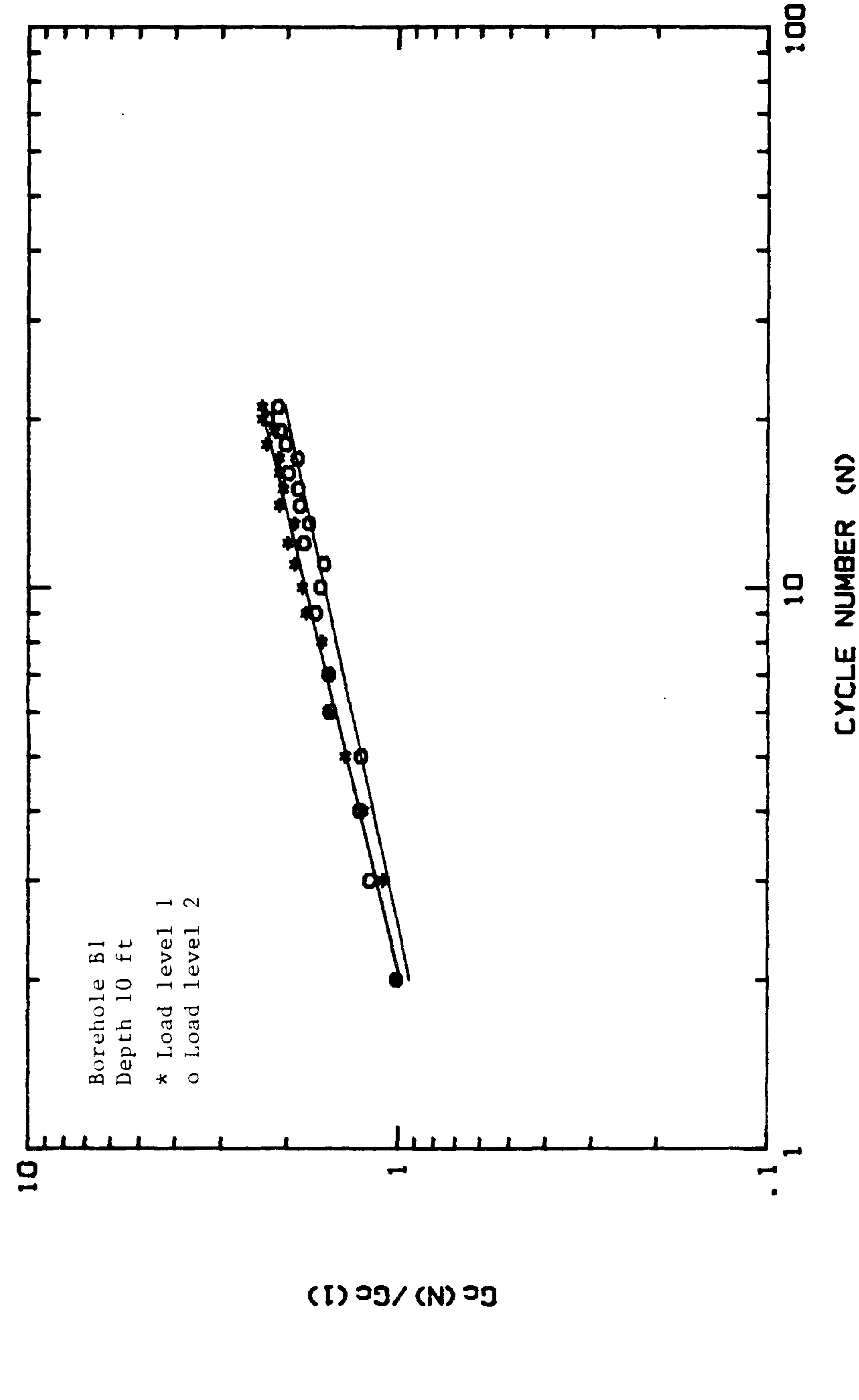

Borehole D1
Depth 9 ft
* Load level 1
o Load level 2
1
10
100
CYCLE NUMBER (N)
10
1
.1
Gc (N) /Gc (1)

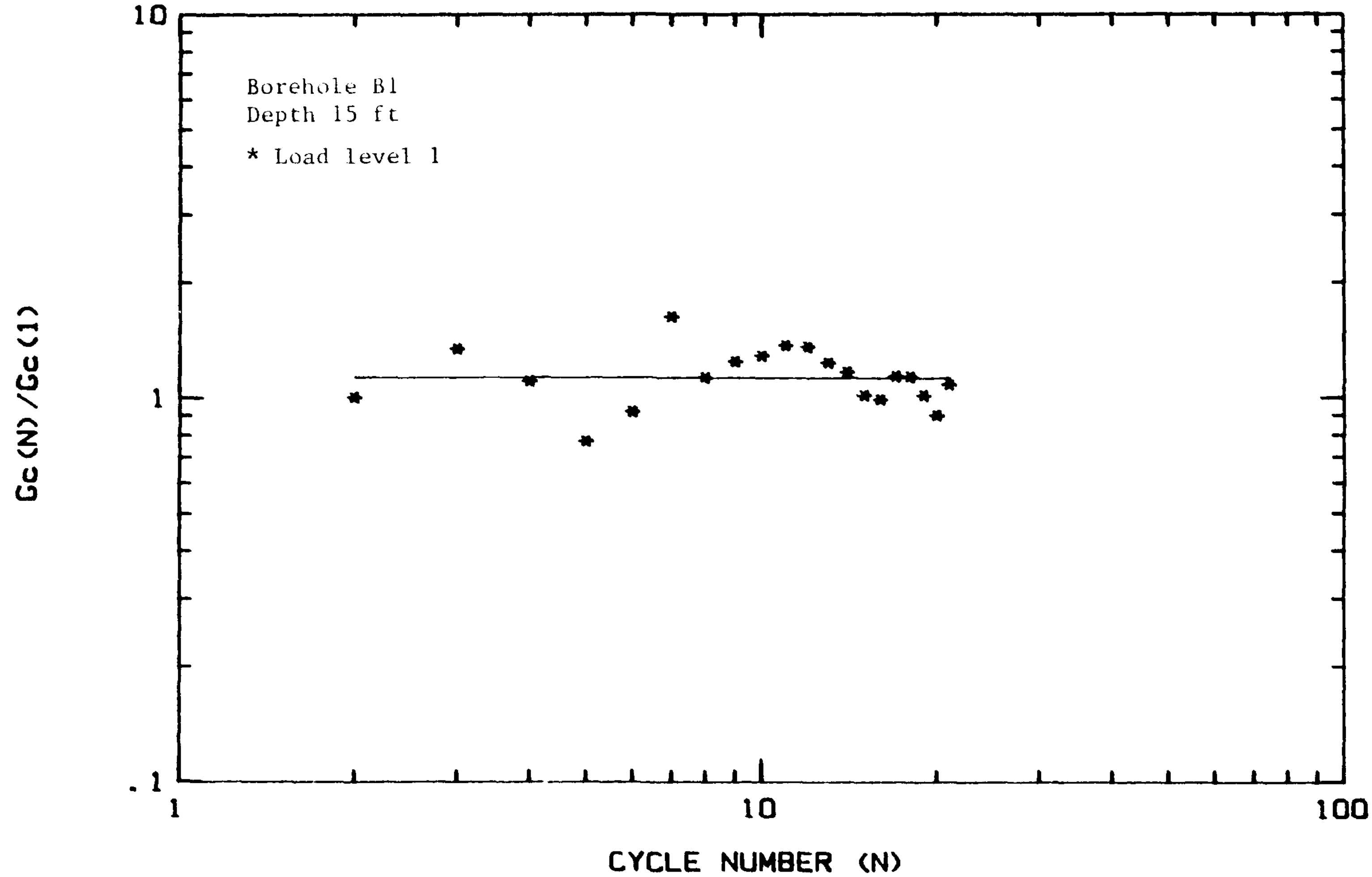

Borehole D1
Depth 13 ft
* Load level 1
o Load level 2
10
1
.1
1
10
100
CYCLE NUMBER (N)
Gc (N) /Gc (1)

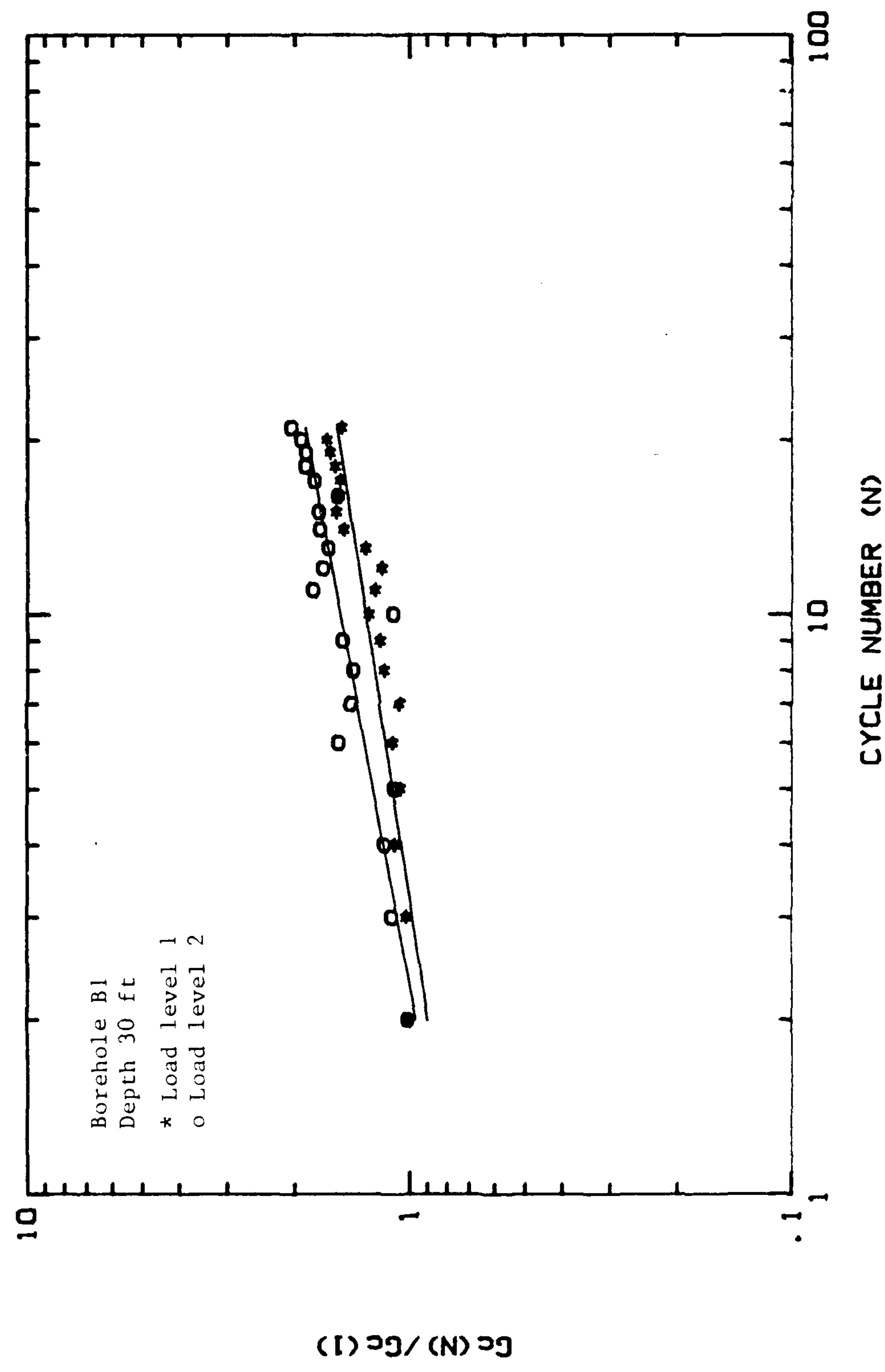

Borehole D1
Depth 17 ft
* Load level 1
o Load level 2
10
1
.1
100
10
CYCLE NUMBER (N)
Gc (N)/Gc (1)

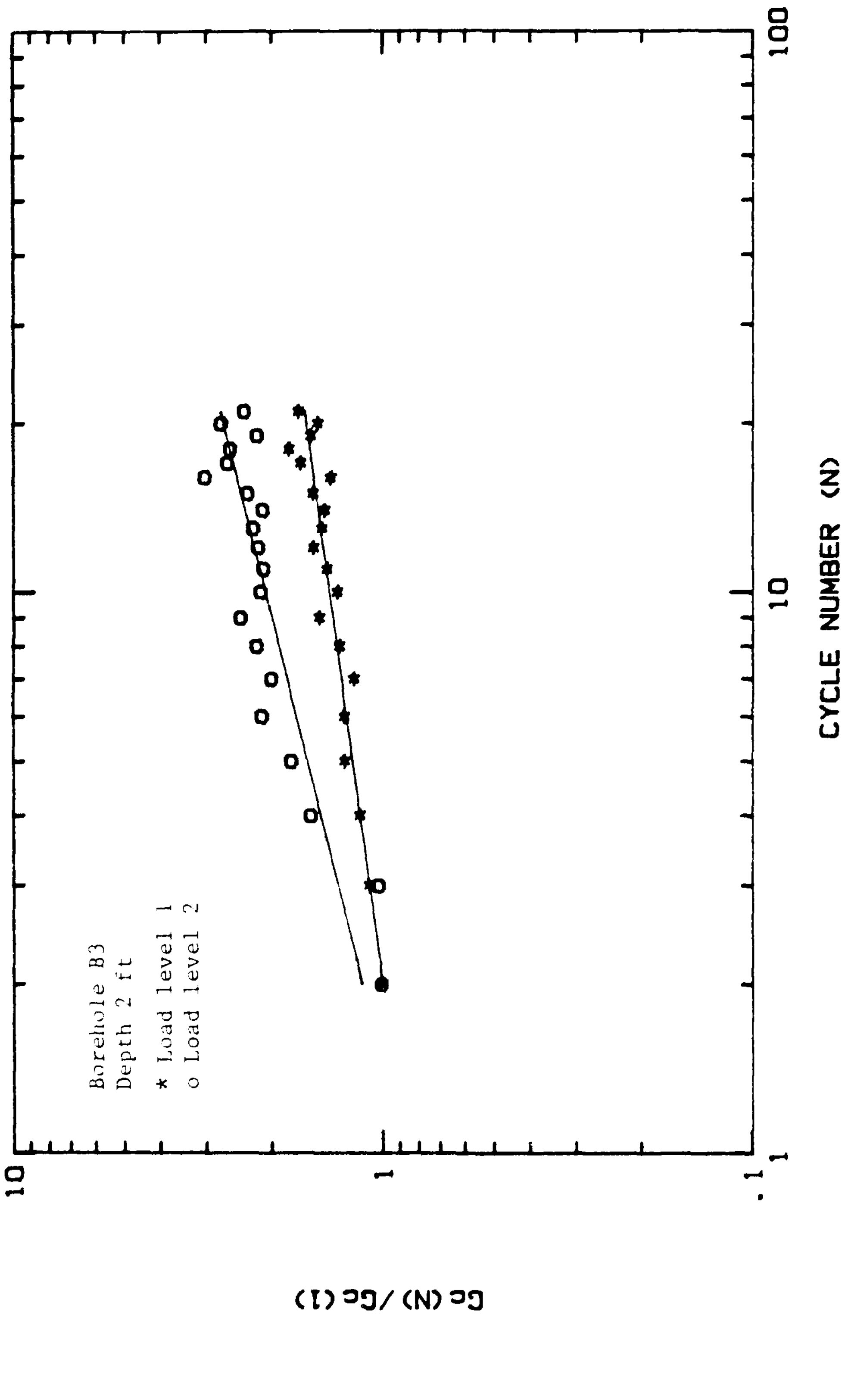

Borehole B2
Depth 2 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
1
10
100
Gc (N) /Gc (1)
.1
1
10

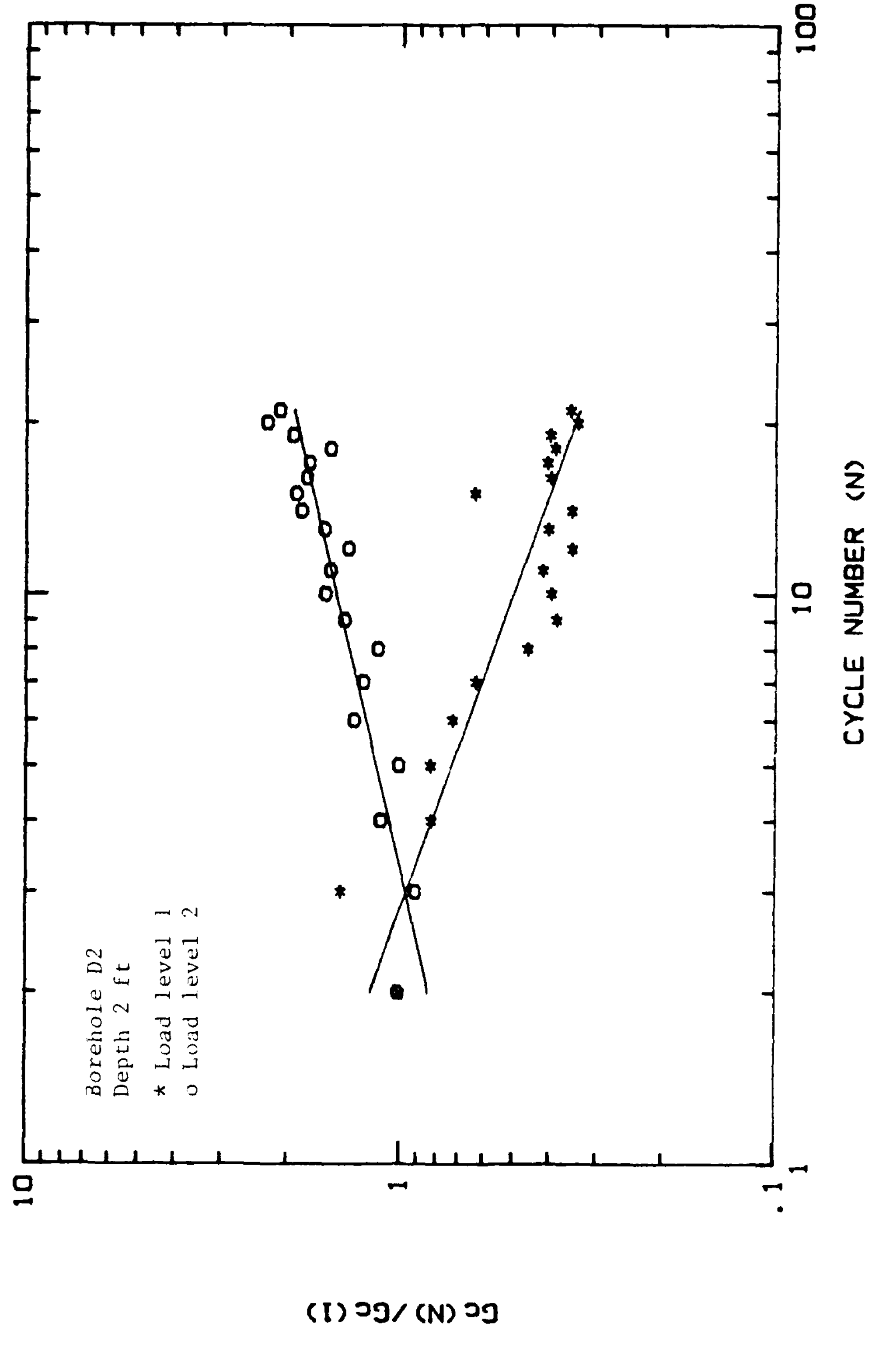

Borehole B1
Depth 7 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
Gc(N)/Gc(1)
1
10
100
.1
1
10


Borehole B1
Depth 10 ft
* Load level 1
o Load level 2
10
1
.1
1
10
100
CYCLE NUMBER (N)
Gc (N)/Gc (1)


Borehole B1
Depth 15 ft
* Load level 1
Gc (N) /Gc (1)
10
1
.1
1
10
100
CYCLE NUMBER (N)


Borehole B1
Depth 30 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
1
10
100
10
1
.1
Gc(N)/Gc(1)


Borehole B3
Depth 2 ft
* Load level 1
o Load level 2
CYCLE NUMBER (N)
1
10
100
.1
1
10


Borehole D2
Depth 2 ft
* Load level 1
o Load level 2
10
1
.1
1
10
100
CYCLE NUMBER (N)
Gc (N) /Gc (1)